JKU

Production Research

Publisher

Johannes Kepler University Linz
O.Univ.-Prof. DI Dr. Richard Hagelauer
Altenberger Straße 69
4040 Linz / Austria

Editor

Univ.-Prof. Mag. Dr. Alois Ferscha
Institute for Pervasive Computing

Layout and Typesetting

Angelika Mayr
Michael Gattinger, BSc.
DI Benedikt Gollan

Graphics

Michael Gattinger, BSc.

Fotos

Michael Gattinger, JKU - Johannes Kepler University, Alfred Mayr, Jasmina Rahmanovic/cityfoto, privat

Contact / Distribution

Univ.-Prof. Mag. Dr. Alois Ferscha
Institute for Pervasive Computing
Johannes Kepler University Linz
Altenberger Straße 69
4040 Linz / Austria
ferscha@pervasive.jku.at

www.pervasive.jku.at
Publication date: 27.05.2016

ISBN: 978-3-200-04583-5

How to cite:

Ferscha, A. (Ed.). (2016). *JKU Production Research*: Johannes Kepler University Linz, Altenberger Straße 69, 4040 Linz, Austria, ISBN: 978-3-200-04583-5, http://www.pervasive.jku.at/download/JKU_PRODUCTION_RESEARCH.pdf

Preface

Dr. Reinhold Mitterlehner
Vice-Chancellor, Federal Minister of Science, Research and Economy

Science and research are key drivers of social development and economic competitiveness. To this end, they need the creative and innovative strengths of universities, research establishments as well as business and industry. Located at the heart of the central Upper Austrian area, the Johannes Kepler University is ideal for carrying out research across the chain of innovation, starting with fundamental research and ending with the final product. Substantial third-party funds provided by enterprises and external partners, more than 34 million euros in 2015 alone, are ample proof of its vital links to industry.

Disciplines such as computer science, mechatronics as well as production and logistics management are major pillars that have grown within the university, while the new focus on production research will enhance work on 'Industry 4.0', a key issue for the future. This kind of industrial change is a challenge to be met jointly by business, politics and society. Thus it will not suffice to intensify the cross-connecting of machines: we also need the appropriate specialists and managers capable of planning and steering these processes, thus making quality training and the professional development of students yet another major task. In close cooperation with industry in the forthcoming years, the Linz Institute of Technology is to be established at the Johannes Kepler University with the intention of pooling and maximising existing capacities and knowledge. This project, which is part of the University's policy to create a distinctive profile, is supported by my Ministry as a future priority under the performance agreement. Its acronym LIT is an ambitious reminder of one of the most famous and most renowned US institutes, namely the MIT. Technology is supposed to serve humanity and research to improve our lives. Nowhere else is this idea being turned into an everyday reality so much as at the Medical Faculty, whereby in addition to the provision of medical services as well as the training and professional development of future doctors, medical and medico-technical research is an essential focus of this newly established faculty.

It will be important, and not only in view of the difficult financial framework, to make the best possible use of existing resources and exploit in-house synergies between the various departments. Cooperation between different fields and institutions will result in entirely new creative approaches, which in turn will provide major innovative potential. As is appropriate for Upper Austria as a knowledge and business location, the Johannes Kepler University must continue to hone its profile and enhance its existing strengths. It is only in this way that the University's research competence can become fully effective.

Dr. Josef Pühringer
Governor of Upper Austria

“The best is to be found where talent and effort combine.”
Johannes Kepler

In the modern knowledge-based society the human being represents the key factor. The innovative strength embodied in the many masterminds of our country must be put to use on the road - like the horsepower of a car: through research facilities, companies and in everyday life. Therefore, we are in need of the hightes level of educational institutions – from kindergartens to universities. In this regard, the implementation of the medical science school in Linz presents another major milestone. But we want to go further: The aim of a comprehensive university is being consistently pursued.

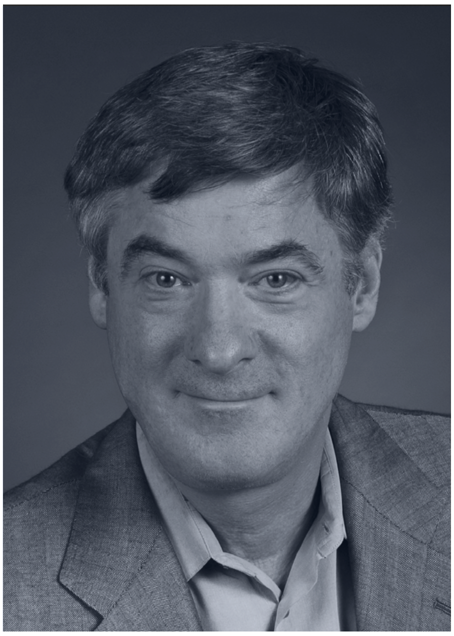
Mag. Thomas Stelzer
Deputy Governor of Upper Austria

Research and innovation form the pillars of a powerful and competitive Upper Austrian economy, which has a long and successful history in industrial production. In order to remain competitive and to strengthen our region’s international position, we must focus on the continuous development of our regional production system. For that reason industrial production processes are one of the key fields of action of our Strategic Economic and Research Programme “Upper Austria 2020“.
In Upper Austria, we strive for technological leadership in the area of industrial production processes and we seek to become one of the leading regions for “interdisciplinary manufacturing research” by 2020. State of the art production research such as conducted at the Johannes Kepler University Linz is thus of utmost importance to the future development and success of our region.

Mag. Dr. Michael Strugl, MBA
Board of Governors of Upper Austria

The upcoming technical and organizational approaches, which are summarized under the notion Industry 4.0, enable entire new added value possibilities and business models. An enduring enhancement of the productivity achieved with technological and organizational improvements is of high importance to strengthen production processes. As Upper Austria – with its share of 26 percent of the total production volume – is the leading industry region in our country. In this context our region has ideal preconditions to become a leading player in the field of industry 4.0 as all the necessary and particular resources and capabilities are already located here: Upper Austria is not only a strong economic hub and home to outstanding businesses, there are as well quite a number of research and development as well as educational institutions in the field of industry 4.0, amongst the Johannes Kepler University Linz is a major and also international well recognized competence center for industrial production processes

Preface



Prof. Dr. Joseph A. Paradiso
Associate Professor of Media Arts and Sciences, MIT Media Laboratory

We're entering an epoch where not only the things we use are undergoing enormous change, but also the way in which these things are manufactured will similarly revolutionize. Most devices already sense aspects of their environment, and increasingly connect back to communicate aspects of what they perceive. Once common standards are evolved that enable them to freely share this data (IMHO, the prime tenant of what is now called 'Internet of Things'), we'll be living in a very different world, where purpose and function begin to seamlessly blend between and beyond devices, and things become a continuous computational substrate.

How devices are made in such a world, where the boundary between the device and the machine that makes it begin to erode, is a very fertile field of research. We're entering an epoch where manual skill alone isn't enough to justify human workers – the seamless combination of human judgment and creativity with mechanical precision and scalability will define the future factory. I've spent over two decades working on today's 'Internet of Things', initially pioneering new kinds of sensors to enable new modes of human-computer interaction, but more recently exploring how human perception and intent graft onto ubiquitous sensing and actuation – essentially how people will couple into the 'electronic nervous system' that now scales out across the planet. My team's recent work have looked at how people interface with everything from smart tools to smart buildings, all of which bear relevance production research.

As such, I'm delighted to witness the strong focus on production research currently displayed at JKU. Prof. Ferscha and his colleagues at JKU Linz have their sight properly set on this exciting future and can rely on a first-class team of researchers and collaborators that will be leading innovators in the ongoing industrial revolution.

Dr. Wolfgang Eder
Chairman of the Management Board of voestalpine AG

More and more machines, workflows, and processes along the industrial value chain are being connected via the Internet. Today many industrial products incorporate technologies which are embedded in networked systems, and by 2020 around 50 billion objects worldwide will be digitally connected. This gives rise to the Internet of Things, a virtual world in which all conceivable items exchange information with each other with various degrees of complexity. This opens up new and hitherto unimaginable opportunities for industry.

Industry 4.0 is not a new trend in the voestalpine Group; it has long been an established practice. Industrial workflows and processes are intelligently connected using digital information and communication technologies, and value chains are optimized in terms of costs and performance, both serving to extend our innovative advantage and technological leadership further. The most recent example of this is our new wire rod mill in Leoben, the most modern of its kind in Europe. The ultimate objective must be to completely digitalize all process stages, from initial order through to final quality control.

Today fully-automated and networked production processes are an essential part of producing high-quality steel and its subsequent processing into high-end products. Production should no longer be conceived of and executed in stages, but instead regarded as an integrated and controlled process which extends along the entire internal value chain and beyond. The potential this offers is enormous: individualized products for sophisticated customers, resource-saving logistics, new and highly efficient services, and a more flexible working environment. The list goes on and on. Our goal is to work towards the concept of a smart factory, in which new technologies and systems are used to increasingly network production processes, both within the Group and beyond, and involving both customers and suppliers equally.

Our world is subject to increasingly rapid change, with shortening product cycles, shifting markets, and the emergence of new technologies. In short, it's a very different world from the one we knew just a few years ago, and in five years it will bear little resemblance to our current world. Disruptive developments, active change, and flexible cooperation define this new era. voestalpine is keeping pace with these changes. It is no longer the company it was ten years ago: We've transformed from an Austrian steel producer to a global technology and capital goods group with almost 50,000 employees working in around 500 companies, in more than 50 countries across 5 continents.

But one thing remains clear: The industry of the future won't be able to manage without people. However, the emphasis will undoubtedly shift away from workers operating machines and towards controlling processes. Industry 4.0 also brings with it a huge evolutionary advance in employee qualifications and activities, as well as redefining the workplace. The future demands a well-educated workforce, particularly in the STEM subjects, with employees prepared to continually refresh their skills and qualifications to reflect technological progress. At the same time, our education system must focus far more strongly on the challenges of permanent technological change than it does today.

At voestalpine we are constantly increasing levels of investment in research and development, creating strong expert networks with national and international universities and research institutions, and engaging in intensive R&D-partnerships with key customers. For us, a well-positioned JKU is a core partner for a wide range of technical areas, particularly in the product and production research process. Over the coming years JKU will play an increasing role in shaping future developments, including those at voestalpine. Together with the Linz Institute of Technology (LIT), a decisive step has been taken in the right direction, making also on international standards a highly sophisticated technical and scientific research and teaching possible on a significantly broader basis.

Preface

Univ.-Prof. Mag. Dr. Meinhard Lukas
Rector of Johannes Kepler University Linz

Upper Austria is among the world's leading regions renowned for competitive manufacturing industries and technological innovation. The Johannes Kepler University of Linz has always sparked and boosted technological advancement in Upper Austria by providing research contributions in natural sciences (physics, chemistry), formal sciences (logic, informatics, mathematics, statistics, systems theory), social sciences, and the applied sciences (mechatronics, electrical engineering), thus underpinning industrial innovation. JKU has been, and will continue to be, Austria's leading university in terms of cooperation with the industrial sector.

The JKU is rooted in industrial research and provides ongoing advancement and breakthroughs in production materials, industrial process developments, experimental design, signal processing, internet-of-things, human-computer interactions and cyber-physical systems. The university also addresses academic issues in sociological and economic research, business intelligence, innovation, quality management, labour, and welfare. This means that the JKU is ideally positioned to create and develop new scientific insight and engineering solutions that can be directly applied to real-world industrial systems and processes.

The newly founded Linz Institute of Technology (LIT) at the Johannes Kepler University aims to bundle all these activities under one strong brand. The LIT is an international competence centre for technological research and teaching. The focus is on product and production process research as well as on the assessment of technology impacts. LIT reflects JKU's many years of experience in science and engineering. The LIT will provide a place where ideas from different scientific disciplines can come together in an innovative, high-performance structure. The brightest minds will develop solutions for future challenges.

Therefore, the JKU's industrial partners can build on cutting-edge research, allowing them to quickly adapt to current trends and support the future requirements of enabling technologies as well as successfully advance state-of-the-art technologies.

The JKU Production Research Whitebook is an excellent example of how our researchers drive the university's strategy of highly cooperative, cross-faculty, interdisciplinary research activities. They combine excellence from diverse fields of expertise and ensure sustainable developments, mutual scientific benefits, and industrial production in Austria over the next decade. I would like to thank the editor, the editorial board and the authors of the JKU Production Research Whitebook. The Whitebook is an outstanding presentation of the JKU's visions and expertise in production related research and development. Our Linz Institute of Technology will bring university research and industrial partners together and provide a place to develop real-world solutions for tomorrow.

o. Univ.-Prof. Dr. Richard Hagelauer
Former Rector of Johannes Kepler University Linz

Since its beginnings, industrial production and product research has been characterized and identified by continual, cutting-edge development. Sometimes, certain innovations are so exceptional that breakthroughs such as these can warrant the use of the term “industrial revolution”. The first revolution was undoubtedly the transition from manual labor to machine production, followed by the second revolution of mechanization and electrification and then by the third revolution by the development of the computer. We now stand on the threshold of the fourth industrial revolution characterized by increasing digitization and the interconnection of products: Industry 4.0!

Industry 4.0 is the intelligent interconnection of products, processes and value chains. It will change the industrial world in a sustainable way; in fact, it is already doing so. There are new opportunities and potential benefits by rapidly increasing opportunities in information and communication technologies. Upper Austria is a location of research and business and there are excellent opportunities here to actively and smartly shape the future of production and other manufacturing and business areas.

The JKU can make significant contributions. In the fall of 2013, during my term as Rector of the Johannes Kepler University, a task force consisting of renowned professors was created to tackle this subject head on. The JKU’s “Task-Force Industry 4.0” is an interdisciplinary group and enriches the fourth industrial revolution process in Upper Austria by providing innovative ideas and contributions. It does this based on extensive and long-standing expertise in the area of production research at our university. This is how the JKU is helping to create the future.

I would like to sincerely thank Dean Prof. Ferscha for his hard work to collect and document these competencies in a “whitebook” and I am pleased that this compendium can now see the light of day.

Preface

Prof. Dr. Gerhard Tröster
Institut für Eletronik, ETH Zürich

I am delighted at the scale of the production research currently investigated at the JKU. It is evident that this institution will continue its leading role in the innovation of ICT, now with a clear focus on the highly relevant research challenges that arise out of the revolution of Europe's industry. The investigations outlined within this document combine the requirements of future production technologies with the ever growing potentials of ICT. During previous collaborations, P. Ferscha and I have experienced first hand the ongoing changes in the research field, especially with respect to novel challenges in industry as well as ICT, which in turn require a broader toolset and offer new opportunities for research.

Prof. José del R. Millán
Swiss Federal Institute of Technology (EPFL), Lausanne

It is impressive to see that the JKU Linz is continuing to deepen its strong academic focus on production research and its formidable challenges. In this whitebook, JKU addresses a critical research field for our society at the crossroads of the foundations of computer science and the principles of added-value manufacturing, intelligent products and components, industrial processes, logistics and sustainability.

Prof. Dr. Paul Lukowicz
Embedded Intelligence, DFKI GmbH

In a few years time, ICT research will be the driving factor in the renewal of industrial processes and production systems. Only the combination of sensors and actuators, coupled with wireless communication capabilities and high computing power, will create the opportunity to automatically observe the real world and map its parameters to the digital domain in a timely fashion. As such, it is impressive to see the level of foresight and expertise demonstrated by the JKU Linz, especially via its support of the research fields pervasive computing and mechatronics, two disciplines that are instrumental for bringing to life the concepts of Industry 4.0.

Prof. Dr. Albrecht Schmidt
Institut für Visualisierung und Interaktive Systeme, Universität Stuttgart

The changes induced by embedded, networked and ubiquitous ICT in industry and production systems are almost inconceivable. The traditional separation between concept, development, distribution, and operation is disappearing. Nowadays, retail customers have a direct connection and impact on the production processes, and are involved in the innovative process. It is a sign of the importance of these challenges, that the JKU, a well-known innovative university, is further deepening its research effort in related areas. The combination of topics outlined in this document is highly challenging and promising with respect to its application in industry and science. It is my pleasure to support my colleagues at JKU Linz in these efforts.

Prof. Dr. -Ing. habil. Alois Knoll
Robotics and Embedded Systems, TU München

The mastery of the processes introduced by novel production research, especially related to the coupling of tightly networked processing systems with physical processes and entities in non-optimal environments and under non-optimal conditions represents the foundational basis of tomorrow's industry and economy. The world is currently at the threshold of a second wave of connectivity that will leave the first far behind. Over the last 20 years, the JKU has always been a strong partner in ICT research, especially within the fields pattern recognition, machine learning, pervasive computing, and mechatronics. In this, the JKU has been a leading innovator in Europe. I can only emphasize the importance of the research challenges outlined within this document and proclaim my full support for the continuation of the important work conducted.

Prof. Dr. Michael Beigl
Lehrstuhl für Pervasive Computing Systems, Karlsruhe Institute of Technology

As professor for pervasive computing at the Karlsruher Institut für Technologie (KIT), I am delighted to see the Johannes Kepler Universität Linz (JKU) continue to address the research challenges that arise from the current revolution in industry and production. In my capacity as researcher, I am actively investigating highly-miniaturized, embedded microprocessor that are equipped with sensors, actuators and wireless communications. Such devices have in recent times found application in industry and drive the development of future, "smarter" products that are represented in- and linked to the digital world. After reading this whitebook, I am confident that JKU Linz will continue to be a leading innovator in these areas.

Preface

Univ.-Prof. Mag. Dr. Alois Ferscha
Institute of Pervasive Computing
Johannes Kepler University Linz

Over the past decade we have witnessed one of the most profound socio-technical phenomena in the evolution of mankind ever: **the blurring of the boundaries between the physical and the digital**. The physical world -made up by objects and processes- has become seamlessly interwoven with the digital world -made up by data representations and computations- at planetary scale and micro level granularity.

Natural science research, systems engineering and a tremendous technological progress in microelectronics and globe spanning data networks have shaped a totally new outreach to how mankind is experiencing information and communication technologies (IT) - in every breath of an individual's life. The nature and appearance of IT is changing to be hidden in the fabric of everyday life, invisibly networked, and omnipresent, with applications and services greatly being based on the notions of knowledge intelligence and cognitive abilities. Interaction with such globe spanning, **pervasive IT systems** apparently happens be more implicit, at the periphery of human attention, rather than explicit, i.e. at the focus of human attention. This shift in paradigm is manifested by the evolution of „aware" IT, i.e. systems with the ability to autonomously sense and perceive, recognize, learn, reason, and even anticipate or predict phenomena and their consequences in the context of its operation.

Referred to as Cyber-Physical Systems (CPS) in the scientific literature, the entanglement of „atoms", i.e. real world physical objects (things, appliances) and processes (manufacturing, transportation, services), and „bits", i.e. their digital data representation and computations in communication networks (the "cyber") is dramatically impacting also economy and manufacturing industries. Digitalization, and consequently virtualization have opened an unexpectedly wide spectrum for possible future scenarios of how we think about **future products** (smart products, digital products, online products), and the **processes and production systems** that create them (smart factories, digital production, online manufacturing). Technology-wise, embedded, wirelessly connected tiny compute platforms equipped with a multitude of miniaturized sensors collect data about the physical world and phenomena, analyze and interpret that data in real time, reason about the recognized context, make decisions, and influence or control their environment via a multitude of actuators. Sensing, reasoning and control, thus, are tightly interconnecting the physical and digital domain, with feedback loops coupling one domain to the other. Physical processes affect background computations, while computations steer the physical realm.

Aside the IT prospect of the physical-digital entanglement however, future product and production systems will also emerge at the confluence of scientific insight coming from other disciplines. European research priorities like the one billion Euro FET (Future and Emerging Technologies) flagship research initiatives in material sciences (Graphene), the Human Brain Project, and very recently the Quantum Technologies flagship are strongly indicative to dramatically change the world -also the industrial world- as we see it now.

Renowned in, and well connected with the international, particularly the European research community, scientists at the Johannes Kepler University Linz (JKU) have played a **pioneering role** in many of the product creation and production systems related research concerns. Among the early JKU contributions are the establishment of a research unit creating and fostering what has become popular over the past three decades worldwide as „Mechatronics", the foundation of (worldwide first) chairs or research departments of „Computational Perception", „Soft-Matter Physics", „Polymer Science and Engineering", „Pervasive Computing", „Information Electronics", „Business Informatics", „Industrial Mathematics", „Innovation Management", and more recently „Very

Large Scale Software Systems“ and „Integrated Quality Design“. Drawing from multiple disciplines like **Computer Science** (Signal Processing, Networked Embedded Systems, Sensor/Actuator Systems, Internet and Web Technologies, Software Architecture and Engineering, Pattern Recognition, Machine Learning, Deep Learning, Data Mining and Knowledge Management, Man-Machine Interaction, Visual Data Analytics), **Physics** and **Chemistry** (Nanostructures, Photonics, Soft-Matter Physics, Polymeric Materials), **Electrical Engineering** and **Mechatronics** (Microelectronics, Wireless Communication, Robotics, Process Automation, Control Theory, Additive Manufacturing, Product Development), **Mathematics** and **Modelling** (Process Modelling, Decision Making, Interoperability of Models, Dependability, Scalability, Predictability, Managing Complexity and Uncertainty, Simulation, Optimization), **Economics** and **Labor** (Financial Mathematics, Business Intelligence, Innovation Management, Quality Assurance, Social Welfare, Labor Policy, Ecology, Sustainability), and **Law** and **Legislation** (Labor Law, Environmental Law, Business Law, Intellectual Property Rights, Legal Gender Studies) JKU scientists have spawned an emerging, topical and vibrant field of research, **adressing the next generation research challenges** of products and production systems.

The Whitebook JKU Production Research -which you hold in your hands now- is an impressive reflection of the **research perspective** on what is referred to as e.g. the “Internet of Things” (IoT), the “Web of Things” (WoT), the “Web of Services” (WoS), “Machine to Machine” (M2M), the “Physical Internet”, the “Industrial Internet” or “Industrie 4.0” in todays business, political, media and press discourse. It unveils the superficiality of this pure technology perspective and the respective popular science mindset. It stands -to the best of our knowledge- as a **first manifesto of a holistic, complementary disciplines production research prospect**, reflecting the outstanding research skills and competencies at JKU. This is evidenced right from the beginning with an assessment and analysis of production research worldwide, relating JKU production research with the mission of comparable efforts in Europe, North America and Asia.

Structured along five **research focus lines**, (i) Smart(er) Materials for Products and Production, (ii) Smart(er) Products and Production Processes, (iii) Future and Emerging Enabling Technologies for Production Systems, (iv) Mastering Complexity in Production and Communication Systems and (v) Product Lifecycle Management and Product Ecosystems, some 27 position statements by JKU researchers or research teams have been posed, outlining specific prospective **research visions**, indicating appropriate research methods and **approaches**, outlining potential **impacts** that the targeted research will have on science, technology and engineering -thus also to industry and economy- and highlighting also the research competencies and infrastructure already established at JKU.

As such, this Whitebook stands as an invitation to the **globe-spanning JKU network of academic research partners** to foster and sharpen collaborative research in the product and production systems domain, to the **JKU world leading industrial and business partners** to cooperatively fuse revolutionary research results and disruptive innovations into the realm of next generation industrial systems, and to the **JKU strategic and political alliances** to seed and fertilize opportunities to make the addressed research visions come true, ultimately for the good of welfare and society as a whole.

I wish to express my sincere respect to former JKU rector Richard Hagelauer for initiating and supporting a production research task force at our university, which stands at the very roots of this Whitebook. My deep gratitude for their respective efforts got to Austria‘s Vice-Chancellor and Federal Minister of Science, Research and Economy Reinhold Mitterlehner, to the representatives of the Government of Upper Austria, Josef Pühringer, Thomas Stelzer and Michael Strugl, and the Chairman of the Management Board of voestalpine AG, Wolfgang Eder. Warm thanks to all my supportive colleagues at universities worldwide, the editorial board, the layout and typesetting team, but most of all to all the contributing authors for the involved and intriguing scientific discourse along the trail of developing this Whitebook. Ultimately, thanks to JKU rector Meinhard Lukas for paving the last mile of this future road from and to JKU.

Authors

O.Univ.-Prof. DI Dr. Wolfgang Amrhein
Institute of Electric Drives and Power Electronics

Univ.-Prof. Mag. Dr. Johann Bacher
Institute of Sociology -
Department of Empirical Social Science Research

A.Univ.-Prof. Mag. Dr. Robert Bauer
Institute of Organization and Global Management Studies

Univ.-Prof. Dr. Siegfried Bauer
Institute of Experimental Physics -
Soft Matter Physics Department

Univ.-Prof. Dr. Oliver Bimber
Institute of Computer Graphics

Univ.-Prof. Mag. Dr. Karl Dörner
Institute of Production and Logistics Management

Assoz.Univprof. Dr. Dmitry Efrosinin
Institute of Stochastics

Univ.-Prof. DI Dr.Alexander Egyed M.Sc.
Institute of Software Systems Engineering

Univ.-Prof. Mag. Dr. Alois Ferscha
Institute of Pervasive Computing

Univ.-Prof. MMag.Dr. Matthias Fink
IFI - Institute of Innovation Management

A.Univ.-Prof.[in] Mag.[a] Dr.[in] Iris Fischlmayr
Department of International Management

Mag. Johannes Gartner
IFI - Institute of Innovation Management

A.Univ.-Prof. Mag. Dr. Paul Grünbacher
Institute of Software Systems Engineering

Dr. Michael Gusenbauer
IFI - Institute of Innovation Management

Univ.-Prof. DI Dr. Kurt Hingerl
Center for Surface and Nanoanalytics (CSNA-ZONA)

Univ.-Prof. Dr. Sepp Hochreiter
Institute of Bioinformatics

A.Univ.-Prof. Mag. DDr. Johann Höller
Department of Data Processing in Social Sciences,
Economics and Business

Univ.-Prof. Dr. Mario Huemer
Institute of Signal Processing

O.Univ.-Prof. DI Dr. Dr.h.c. Hans Irschik
Institute of Technical Mechanics

Univ.-Prof. DI Dr. Bernhard Jakoby
Institute of Microelectronics and Microsensors

Univ.-Prof. Mag. Dr. Bert Jüttler
Institute of Applied Geometry

Univ.-Prof. Dr. Norbert Kailer
Institute of Entrepreneurship and Organizational Development

Assist.-Prof.[in] Mag.[a] Dr.[in]
Elisabeth Katzlinger-Felhofer
Department of Data Processing in Social Sciences,
Economics and Business

Univ.-Prof. Dr. Thomas Klar
Institute of Applied Physics (IAP)

Univ.-Prof. Dr. Erich Peter Klement
Department of Knowledge-Based Mathematical Systems

Univ.-Prof. Dr. Reinhold Koch
Institute of Semiconductor and Solid State Physics

A.Univ.-Prof. DI Dr. Josef Küng
Institute of Application Oriented Knowledge

O.Univ.-Prof. DI Dr. Ulrich Langer
Institute of Computational Mathematics

Univ.-Prof. Mag. Dr. Gerhard Larcher
Institute of Financial Mathematics

Mag.a Dr.in Daniela Maresch LL.M.
IFI - Institute of Innovation Management

Univ.-Prof. DI Dr. Jürgen Miethlinger MBA
Institute of Polymer Extrusion and Compounding

O.Univ.-Prof. DI Dr. Dr.h.c. Hanspeter Mössenböck
Institute of Systemsoftware

Univ.-Prof. Dr. Werner Müller
Department of Applied Statistics

A.Univ.-Prof. DI Dr. Timm Ostermann
Institute of Integrated Circuits

Univ.-Prof. Dr. Peter Paule
Research Institute of Symbolic Computation

A.Univ.-Prof. Mag. Dr. Johannes Pedarnig
Institute of Applied Physics (IAP)

Univ.-Prof.in Dr.in Susanne Pernicka
Institute of Sociology - Department of Economic and Organisational Sociology

O.Univ.-Prof. Mag. Dr. Helmut Pernsteiner
Department of Finance - Corporate Finance

A.Univ.-Prof. Mag. Dr. Reinhold Plösch
Department of Business Informatics - Software Engineering

O.Univ.-Prof. DI Dr. Gustav Pomberger
Department of Business Informatics - Software Engineering

Univ.-Prof. Dr. Ronny Ramlau
Institute of Industrial Mathematics

Univ.-Prof. Dr. Armando Rastelli
Institute of Semiconductor and Solid State Physics

O.Univ.-Prof. DI Dr. Wolfgang Samhaber
Institute of Process Engineering

O.Univ.-Prof. DI Dr. Rudolf Scheidl
Institute of Machine Design and Hydraulic Drives

O.Univ.-Prof. DI Dr. Kurt Schlacher
Institute of Automatic Control and Control Systems Technology

O.Univ.-Prof. Mag. Dr. h.c. Friedrich Schneider
Department of Economics

O.Univ.-Prof. DI Dr. Michael Schrefl
Department for Business Informatics - Data & Knowledge Engineering

Univ.-Prof. DI Dr. Andreas Springer
Institute of Communications Engineering and RF-Systems

O.Univ.-Prof. DI Dr. Christian Stary
Department of Business Informatics - Communications Engineering

Univ.-Prof. DI Dr. Georg Steinbichler
Institute of Polymer Injection Moulding and Process Automation

Univ.-Prof. DI Dr. Andreas Stelzer
Institute of Communications Engineeringand RF-Systems

Assist.-Prof. DI Dr. Marc Streit Bakk.
Institut of Computer Graphics

Ass.-Prof. DI Dr. Rainer Weinreich
Department of Business Informatics - Software Engineering

Univ.-Prof. DI Dr. Gerhard Widmer
Institute of Computational Perception

Univ.-Prof. DI Dr. Bernhard Zagar
Institute of Measurement Technology

O.Univ.-Prof. DI Dr. Klaus Zeman
Institute of Mechatronic Design and Production

Table of Contents

Production Research World Wide

Overview of production rese

arch initiatives world-wide

To give an overview of (ICT-related) production research initiatives, world-wide efforts are presented according to their location from west to east, with special focus on Europe and Austria:

North America

The US-American Science, Economy and Industry Politic has identified innovative technology and intelligent automation as a core piece for future competitiveness in the international market for western countries [1, 2]. Hence, in 2007 the **President's Council of Advisors on Science and Technology** (PCAST) launched the research initiative **Cyber Physical Systems** (CPS, collaborating computational elements controlling physical entities) [3] with the purpose of reorienting the R&D Roadmap in ICT (NITRD) [4]. In turn, CPSs became a top priority within national science and innovation funding programs and CPSs are expected to play a key role within all industrial sectors in the future. Further related initiatives within the US are: **Advanced Manufacturing Partnership 2.0, Smart Manufacturing Leadership Coalition, Research Center for Advanced Manufacturing (RCAM), Commonwealth Center for Advanced Manufacturing, Industrial Internet Consortium®**.

Europe (EU)

The mission of the **European Factories of the Future Research Association (EFFRA)** is to lead small and medium sized businesses to international competitiveness based on **FoF** (Factories of the Future) and **PPP** (Public-Private Partnership) [5] initiatives, supported by the EU, in the **Horizon 2020 Program** with 1.15 bn Euros. R&D investment related to Smart Manufacturing, Smart Factories or Smart Products are positioned with various specialized research programs (**FoF, LEIT Call1, FETPROACT 2**). **ARTEMIS** Industry Association is a joint undertaking between industry, universities and research centers to steer cyber-physical systems research by public bodies in Europe. The ARTEMIS-related **ECSEL** project calls from 2015 featured the following topics: Smart Mobility/Society/Energy/Health/ Production/System Integration, Design Technology and CPS. The **European Institute of Innovation & Technology (EIT)** is working on extending its existing portfolio of KICs (Knowledge and Innovation Communities) by "Added Value Manufacturing" and addressing the need for creation of profitable & intelligent manufactories.

Germany:

Germany has declared Industrie 4.0 a leading topic [6] to be pursued by government funding. The BMBF and BMWi are co-funding the "**Zukunftsprojekt Industrie 4.0**" which tackles four fields of action: (i) penetration of I4.0 Technologies in SME, (ii) definition of standards and IT-Architectures, (iii) IT Security in I4.0 and (iv) how to qualify current workers for next generation work. Furthermore, there are several research centers targeting production and products of the future: RWTH Aachen's Cluster of Excellence "**Integrative Production Technology for High-Wage Countries**", **Fraunhofer SIT** "**Cyber-Physical Systems**", **DFKI SmartFactory**, "**Intelligente Technische Systeme**" (it's OWL), **Fraunhofer SmartFactory** and many more.

Austria:

Austria divides funding for research in production and products between the Federal Ministry for Transport, Innovation and Technology (BMVIT) and Federal Ministry of Science, Research and Economy (BMWFW) and is influenced by the **National Platform for Industry 4.0**. The main research program is called "**Produktion der Zukunft**", however the program "**IKT der Zukunft**" has as well identified CPSs as a focus. Austria currently conducts a national preparatory action to establish a knowledge and innovation community (KIC) on "**Added Value Manufacturing**" (AVM) in the frame of the **European Institute of Technology (EIT)**. The **KIC AVM** Initiative proposal will be submitted in 2016, to be established and to start as a CLC (Co-Location Centre in Austria) in 2017.

Fraunhofer Austria Research GmbHs Visual Computing and Production and Logistics Management subareas are **cooperating with the TU Wien** since 2013 **on Industry 4.0**. Key areas for their joined effort are: "Roadmapping", "Design of Cyber-Physical Assembly Systems", "Added-Value Chain for additive production", "resource efficient production design", "Improving Added-Value Design and factory planning tools", "Cyber-Physical Equivalence", "Immersive Environments", "Multi-touch Technology" and Human-Machine-Interfaces [7]. Additionally, the TU Wien was granted an endowed professorship of the marshal plan anniversary foundation in the area of "**Production and Industry 4.0**", a doctoral collage on **Cyber-Physical Production Systems** and a pilot factory "**Pilot-Demonstrationsfabrik**".

In 2011, the **University of Graz** established the initiative "**Smart Production Graz**" (SPG) at the faculty of Mechanical Engineering. At the institutes of "Industrial Management and Innovation Research" and "Production Science and Management", Industrie 4.0-related research is performed in several research projects. A derived concept on the "digital factory" makes use of the highly connected industrial manufacturing process in order to make fast, correct and flexible offers for customers. Another research project is working on the agility of factories from the OEMs and supply chain industry. Various other institutes are working with the SPG in the project "**Smart Shuttle**", which addresses an intelligent, self-driving, communicating shuttle system for in-house logistic in a factory [8].

Salzburg Research is working on semantic models and web-based applications based on those models. Previous work between 2006 and 2009 by SR established a generic model for mechanical products and processes and a model for administration of digital content. Based on the change in industrial research agenda of the EU and Austria SR is renewing their effort to provide **semantic representation of industrial artefacts** [9].

Since 2014, the University of Innsbruck has established an **endowed professorship** by the Marshall Plan anniversary foundation (MPAF) for "**Advanced Manufacturing**". This professorship is supported by a large industrial consortium consisting of Getzner Textil AG, Fussenegger und Grabher Textilveredlung, Benninger AG, Alge Elastic, Schoeller GmbH and the society for promotion of R&D in the textile economy. The research direction is headed towards new production techniques for flexible technical textiles, lightweight construction, textile-supported composites and sensors or textile electrodes.

Also funded by MPAF the **Montanuniversität Leoben** was granted an **endowed professorship on "high-performance materials"** with the support of voestalpine AG and Ebner Industrieofenbau with the goal of improving steel materials via an integrative approach to lead to new alloy and processing concepts for automotive, energy, transport and environmental care sectors.

The federal province of **Upper Austria** is seen as the leading economic and industrial force in Austria. 60% of Upper Austria's products are targeting international markets with an export ratio of 25%. During the crisis year 2013, Upper Austria had the lowest unemployment rate (5.1%) of Europe. With a research quota of 2.79% and still rising, Upper Austria is **focusing on industrial research**. In 2010, 80% of regional R&D investment were taken by industrial companies and UA is the leader of patent applications for the last years. The country is taking advantage of its well-established research institutes and universities - with on the one hand 30.000 Students being educated by its 8 universities and on the other hand 24 extramural research organizations and 11 competence centers additionally advancing R&D.

Leading in the research landscape is **Johannes Kepler University (JKU) Linz** as the biggest scientific institution of Upper Austria. The young university (since 1966) is a driving momentum for science, economy and society with 60 field of studies and 19.000 students, being given a modern and practical education. The research performed by the four faculties (Engineering-Nature, Social-Economy, Law, Medical) and its 119 Institutes (120 Professors, 1800 scientific staff) are internationally acknowledged e.g. by the "Times Higher Education 100 Under 50" ranking for four years in a row. The annual budget of about 100 M€ is topped with additional third party funding of 35 M€. The JKU is **highly engaged** in an industrial R&D strategy called **JKU Production Research** with the following research areas: (i) Smart Materials for Products and Production, (ii) Smart Products and Production Processes, (iii) Future and Emerging Enabling Technologies for Production Systems (iv) Mastering Complexity in Production and Communication Systems, (v) Product Lifecycle Management and Product Ecosystems, which will be presented in detail in the following chapters.

Other European Countries:
Almost all other European countries have a research agenda to promote the Factory of the Future: UK's **High Value Manufacturing**, Belgium's **Made Different**, Portugal's **PRODTECH**, France's **Usine de future**, Italy's **Fabbrica Intelligente**, Sweden's **Produktion 2030**, Netherlands **Smart Industry,** Finland's **Industrial Internet Business Revolution**, Russia's **Solkov Foundation** and the Russian State Scientific Center for **Robotics and Technical Cybernetics** (RTC), Poland's **INNOMOTO** and **INNOLOT.**

Asia (China)

With **Advanced Manufacturing Technology in China: A Roadmap to 2050,** China as production leader in Asia, defined different ways to shape the coming industrial revolution. The roadmap orients itself on its western counterparts like Europe and the USA, with paradigms like "smart production" or "smart factories" [10]. According to the Chinese Academy of Science, which defines the innovation direction for development of intelligent production systems, research activities for high-end production systems are funded, e.g. 3D-Printing [11]. Leading institutions in this field are the **Shenzhen Institute of Advanced Technology (SIAT),** the **Changzhou Advanced Manufacturing Technology R&D and industrial center** in the Shanghai area, the **Institute of Automation (CASIA)** and **Institute of Microelectronics (IMECAS)** in Beijing, **Shanghai Institute of Microsystem and Information Technology (SIMIT)**. Generally, the **Next Generation ICT** research agenda by China's Ministry of Industry and Information Technology is to enhance independent innovation, accelerate the industrialization of scientific and technological achievements and to seize an economic and technological high ground within production systems.

	Institution	Field of Research	Mission
Research Centers	**Centre for Smart Manufacturing (CSM) [12]**	High-Performance Manufacturing, ICT-Enabled Intelligent Manufacturing	Sustainability of manufacturing (electrical, software, processes)
	Research Center for Adv. Manufacturing (RCAM) [13]	Materials and manufacturing processes, laser based 3D printing, welding	promote and apply university lead R&D in partnership with industry
	Commonwealth Center for Adv. Manufacturing [14]	Surface Engineering, Manufacturing Systems, Materials, Welding	Transform applied research into business advantages
	DFKI SmartFactory [15]	production with high variability, small lot sizes	Realization of 4th industrial revolution
	Cluster of Excellence „Integrative Production Technology for High-Wage Countries" [16]	individualization, virtualization hybridization, and the self-optimization of production technology	developing the fundamentals of a sustainable production strategy and theory, as well as the necessary technological approaches
	Frauenhofer Smart Factory [17]	Integration of ICT in automation of adaptable, efficient, reconfigurable production systems	Research & Demonstration Platform for Industrie 4.0 topics
	Russian. State Scientific Center for Robotics and Technical Cybernetics (RTC) [18]	mechanical and electrical robotics, space engineering and technologies	established the engineering principles for robotic systems, intended to operate in the extraordinary conditions
	Institute of Automation (CASIA) [19]	robotics, machine learning, distributed control	Research on intelligent service robots
	Inst. of Microelectronics (IMECAS) [20]	Integrated Circuits, System-On-Chip, Nanoel.	industry-oriented research
	Shanghai Institute of Microsystem and Information Tech (SIMIT) [21]	Materials (functional, magnetic, semi-conductor), wireless communication,sensors (MEMS)	industry-oriented research
	Advanced Manufacturing Center CRC [22]	intellectual property and intangible assets	lead Australian manufacturing innovation, sustainability and competitiveness
Government Initiatives	**Cyber-Physical Systems (CPS) [3]**	collaborating computational elements controlling physical entities	reorienting the R&D Roadmap in ICT
	H2020 Program [23]	Sub-programs: (i) Industrial Leadership (ii) Factory of the Future, (iii) KET: Advanced Manufacturing	Framework program for European research and innovation
	Autonomik für Industrie 4.0 [24]	Technology program of BMWi	Connect latest ICT with industrial prod.
	Smart Service World [25]	sophisticated internet applications including cloud computing, e-health and e-Learning	value chains that exist beyond the smart factory gates, smart services
	Zukunftsprojekt Industrie 4.0 [26]	(i) standards & IT architectures (ii) IT security, (iii) Qualification (iv) mid-sized sector support	Ensuring global competitiveness, designing industrial revolution
	High Value Manufacturing [27]	gap between technology & commercialization	7 centers access to world-class equipment, expertise and collaboration
	Smart Industry (NL) [28]	(i) Capitalizing on existing knowledge (ii) Accelerating in Field Labs (iii) Strengthening the foundation	make the industry more competitive through faster and better utilization of the opportunities ICT has to offer
	Made Different [29]	Individualization, small lot sizes, sustainability	Support national industry
	Fabbrica Intelligente [30]	Technology transfer, infrastructures	Implementation of R&I strategy
	L'usine du future [31]	production research & engineering	reorienting the R&D Roadmap in ICT
	Innolot, Innomoto [32]	R&D in the automotive/aviator industry	Support national industry
	Industrial Internet Consortium [33]	reference architectures/frameworks for interoperability, global development standards, facilitate exchange of ideas, practices, security	(i) drive innovation through creation of new use cases and testbeds for real world applications
	Next Generation ICT [34]	(i) information technology industry, (ii) high-end equipment manufacturing industry, (iii) new materials,(iv) new energy-automotive industry	enhance independent innovation, accelerate industrialization of scientific and technological achievements
	Made in China 2025 [35]	(i) to improve innovation in manufacturing, (ii) to integrating industry and technology	Ten year research plan to restructure the whole industrial production sector
	Manufacturing Industry Innovation 3.0 Strategy [36]	IoT, industrial safety and energy management services	(i) creation of industrial convergence, (ii) boosting innovation infrastructure
	Industrial Value Chain Initiative [37]	IoT and automation technology to fuse manufacturing and IT together	(i) increase education and training, (ii) R&D on fused manufacturing and IT

	Institution	Field of Research	Mission
	Advanced Manufacturing Partnership 2.0 [38, 39]	activities that (i) depend on information, automation, computation, software, sensing, and networking, and/or (ii) make use of cutting-edge materials and technologies	(i) securing technology leadership of the USA, (ii) maintenance of high-skilled jobs, (iii) increasing worldwide competitiveness
	Smart Manufacturing Leadership Coalition (SMLC) [40]	identification and closure of technology gaps in the production landscape of the USA encouraging science – industry collaboration	(i) reducing costs based on data analytics, (ii) infrastructure for ICT, (iii) creation of sensor fusion systems
	Artemis JU, ECSEL JU [41]	Smart Production, Semiconductor Process, Equipment and Materials; Design Technology and Cyber-Physical Systems.	steer embedded & cyber-physical systems R&I actions in Europe
	EFFRA [42]	(i) development of key technologies and (ii) the creation of new high-quality individualized products in a demand-driven industry with optimized resources	lead small and medium sized businesses to international competitiveness
	MANUFUTURE [43, 44]	General survey platform for identification of research requirement in industrial production	transform of industry for a major share of world manufacturing output
	Nationale Plattform Industrie 4.0 Österreich [45]	(i) penetration of I4.0 technologies in SME, (ii) definition of standards and IT-Architectures, (iii) IT Security (iv) worker qualification	Coordination of regional, national and international levels to succeed in the approaching industrial revolution
	Plattform Industrie 4.0 Oberösterreich [46]	(i) Modelfabrik Industrie 4.0, (ii) Innovation assistants (iii) Call "Produktionsstandort 2050"	Supporting of initial implementation of Industrie 4.0 tech. in KMU environment

Products research **Products Engineering** **Production Research** **Production Engineering**

Table 1 Overview on international initiatives on Industrie 4.0, Smart Manufacturing, Advanced Manufacturing, etc. In order to compete on the international R&D level it will be necessary to target both product- and production research, thereby placing Austria on par with the western focus on production as well as the eastern focus on products.

References

[1] President Obama Calls for Smart Manufacturing, http://smartmanufacturing.com/2012/11/07/president-obama-calls-for-smart-manufacturing/

[2] Report to the President on capturing domestic competitive advantage in advanced manufacturing, http://www.whitehouse.gov/sites/default/files/microsites/ostp/pcast_amp_steering_committee_report_final_july_17_2012.pdf

[3] Cyber Physical Systems, https://www.nitrd.gov/nitrdgroups/images/6/6a/Cyber_Physical_Systems_%28CPS%29_Vision_Statement.pdf

[4] Welcome to the NITRD Program, https://www.nitrd.gov/

[5] Factory of the Future Fact Sheet, http://ec.europa.eu/research/press/2013/pdf/ppp/fof_factsheet.pdf

[6] Rede der Bundeskanzlerin zur Eröffnung der Hannover Messe 2014, http://www.bundesregierung.de/Content/DE/Rede/2014/04/2014-04-07-merkel-hannover-messe.html

[7] Industrie 4.0: Potentiale, Chancen und Möglichkeiten, https://www.wko.at/Content.Node/branchen/w/Industrie-4-0_-Sihn.pdf

[8] Industrie 4.0 – Die Produktion der Zukunft, http://lampx.tugraz.at/~i371/industrie40/7521_0_DieProduktionderZukunft_Christian-Ramsauer.pdf

[9] Industrie 4.0, http://www.salzburgresearch.at/papers/industrie-4-0/

[10] Smart Factory 1.0 is helping China's industry to upgrade, http://www.controleng.com/single-article/smart-factory-10-is-helping-china-s-industry-to-upgrade/99453551b21b649559dad2fe91d68708.html

[11] Nepcon China 2014 has successful run in Shanghai, http://www.nepconchina.com/en/News_Center/Event_News/news2014061802/

[12] Conestoga Centre for Smart Manufacturing http://www.conestogac.on.ca/research/centres/manufacturing.jsp

[13] Research Center for Advanced Manufacturing, http://www.smu.edu/Lyle/Centers/RCAM

[14] Commonwealth Center for Advanced Manufacturing, http://www.ccam-va.com/

[15] Smart Factory Laboratory, http://www.dfki.de/web/living-labs-de/living-lab-smartfactory

[16] Integrative Production Technology for High-Wage Countries, https://www.rwth-aachen.de/go/id/bktz/lidx/1

[17] Smart Factory OWL, http://www.iosb.fraunhofer.de/servlet/is/22756/

[18] Russian State Scientific Center for Robotics and Technical Cybernetic, http://www.rtc.ru/

[19] Institute of Automation, http://www.sume.at/casia

[20] Institute of Microelectronics of Chinese Academy of Sciences (IMECAS), http://english.ime.cas.cn/

[21] Shanghai Institute of Microsyste And Information Technology, Chinese Academy of Sciences, http://english.sim.cas.cn/au/

[22] Advanced Manufacturing Cooperation Research Center, http://amcrc.com.au/about

[23] Horizon 2020: The EU Framework Programme for Research and Innovation, http://ec.europa.eu/programmes/horizon2020/

[24] Automatik für Industrie, http://www.autonomik40.de/Was%20ist%20Autonomik%20fuer%20Industrie%2040.php

[25] Smart Service Welt – Internetbasierte Dienste für die Wirtschaft, http://www.bmwi.de/BMWi/Redaktion/PDF/Publikationen/smart-service-welt-internetbasierte-dienste-fuer-die-wirtschaft,property=pdf,bereich=bmwi2012,sprache=de,rwb=true.pdf

[26] Zukunftsprojekt Industrie 4.0, https://www.bmbf.de/de/zukunftsprojekt-industrie-4-0-848.html

[27] Catapult High Value Manufacturing, https://hvm.catapult.org.uk/

[28] Smart Industry, http://www.smartindustry.nl/eng/

[29] Made Different, Factories of the Future, http://www.madedifferent.be/

[30] Fabbrica Intelligente, http://www.fabbricaintelligente.it/chi-siamo/mission/

[31] Plants of the Future, http://www.plantsofthefuture.com/en/home/homepage.jsp

[32] The National Centre for Research and Development, http://www.ncbr.gov.pl/en/

[33] Industrial Internet Consortium, http://www.iiconsortium.org/working-committees.htm

[34] ICT Innovation Policy in China: A Review, http://www2.itif.org/2014-china-ict.pdf

[35] Made in China 2025, http://csis.org/publication/made-china-2025

[36] Korean version of " Industry 4.0 " with and learn a lesson from the place ?, http://www.hihuadu.com/2015/05/08/korean-version-of-industry-40-with-and-learn-a-lesson-from-the-place-21636.html

[37] Industrial Value Chaim Initiative, http://www.iv-i.org/

[38] President Obama launches Advanced Manufacturing Partnership Steering Committee, http://www.whitehouse.gov/the-press-office/2013/09/26/president-obama-launches-advanced-manufacturing-partnership-steering-com/

[39] Made in America: The Next-Generation of Innovations, http://manufacturing.gov/advanced_manufacturing.html

[40] Smart Manufacturing Leadership Coalition, https://smart-process-manufacturing.ucla.edu/about/news/Smart Manufacturing 6_24_11.pdf

[41] ARTEMIS, http://www.artemis-ju.eu/home_page

[42] EFFRA Participates in Latest Digitising Industry Round Table, http://www.effra.eu/

[43] Manufuture-EU, Assuring the future of a competitive and sustainable manufacturing in Europe, http://www.manufuture.org/manufacturing/

[44] Manufuture-EU, http://www.manufuture.at/plattform/manufuture-eu/

[45] Industrie 4.0 Österreich – die Plattform für intelligente Produktion, http://www.feei.at/feei-netzwerk/industrie-40-oesterreich-die-plattform-fuer-intelligente-produktion

[46] Plattform Industrie 4.0 macht Oberösterreich fit für (R)Evolution der Produktion, https://www.land-oberoesterreich.gv.at/Mediendateien/LK/PK_LR_Dr._Strugl_18.7.2014_Internet.pdf

[33] Advanced Manufacturing Cooperation Research Center, http://amcrc.com.au/about

Focus Line 1:
Smart(er) Materials for Products and Production

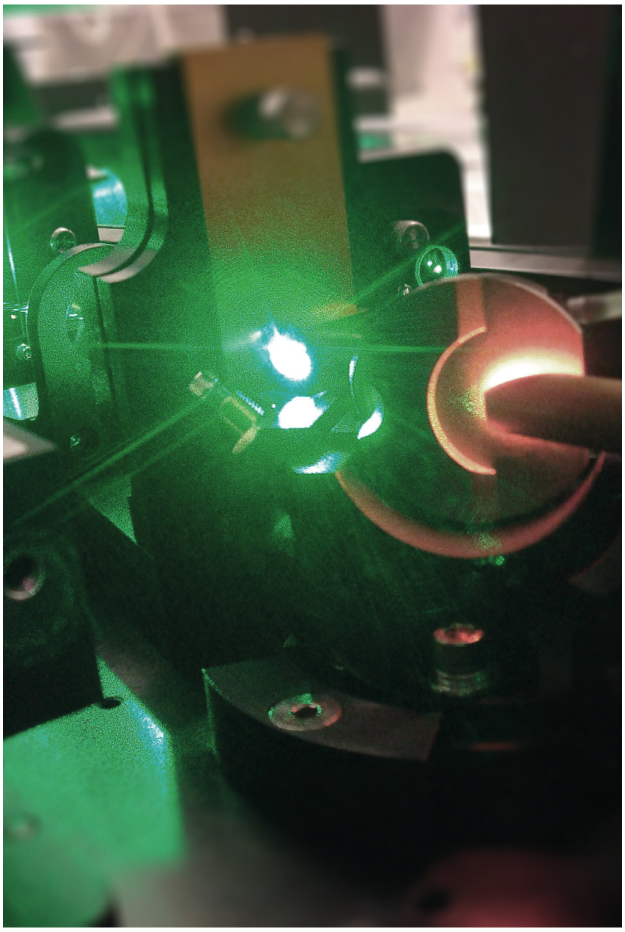
FL1-01 **Photonic Materials**
Coordinator: Institute of Applied Physics (IAP), Institute of Semiconductor and Solid State Physics (HFP)

FL1-02 **Soft Active Materials**
Coordinator: Siegfried Bauer, Institute of Experimental Physics, Soft Matter Physics Department

FL1-03 **Materials Science and Analysis**
Coordinator: Center for Surface and Nanoanalytics (CSNA-ZONA), Institute of Applied Physics (IAP)

FL1-04 **Nanostructured Quantum-Electronic, Optic, Magnetic and Spintronic Materials**
Coordinator: Armando Rastelli, Institute of Semiconductor and Solid State Physics

Photonic Materials



"Consequently, photonics must be considered as a key enabling technology, and it is evident that progress in photonics will demand also progress in materials science."

Thomas Klar

Focus Line 1:

Smart(er) Materials for Products and Production

Coordinators:

Univ.-Prof. Dr. Thomas Klar
Institute of Applied Physics (IAP)

thomas.klar@jku.at - http://www.jku.at/applphys/

Univ. Prof. Dr. Armando Rastelli
Institute of Semiconductor and Solid State Physics

armando.rastelli@jku.at - http://www.jku.at/hfp

Research Focus

- Nanostructured Photonic and Optoelectronic Materials
- Integrated Optics
- Single- and Entangled Photon Sources
- Photonic Materials for Biosensing and Physiological Research

Vision

While the electron was the major player in the 20th century, the **photon is considered to take over** in many areas of every day's life. Already now, long and intermediate range telecommunication is almost entirely based on glass fiber networks, displays and touch screens are important (optical) interfaces and photonics-based lighting will outrange the classic incandescent or fluorescent-tube based technologies very shortly, being a huge step towards more energy efficiency. Lasers are ubiquitous and included in: CD and DVD drives, blue-ray players, bar code readers, pointers and so forth. Lasers are also playing an ever growing factor in smart production as tools for welding, cutting and inscribing as well as in medical technology. For optical communication, also sources of non-classical light (single and entangled photons) are gaining attention for increased security in data transmission.

Consequently, **photonics** must be considered as a **key enabling technology**, and it is evident that progress in photonics will **demand also progress in materials science**. Photonic micro- and nanomaterials are considered to show a huge potential in revolutionizing optics and photonics. They will enable novel forms of light-matter interaction. Composite materials, artificially assembled from several different classes of materials which naturally do not come together, bear the potential to control and manipulate light in a way not possible for the constituent materials on their own.
Further, the standard materials for present photonics, which are mostly pure dielectrics, are bound to diffraction and hence integration and miniaturization is limited to the size of the wavelength of light. Novel photonic metamaterials are promising candidates for materials where the diffraction limit might become irrelevant. Besides the ability of breaking the current limitations in the spatial coordinate, photonic devices hold promise for ultrafast switching, ultimately limited by the frequency of (visible) light, which is in the range of 500 THz, orders of magnitude faster than current electronic switches.
While conventional photonic devices are usually fabricated by highly elaborate and expensive technologies, adopted from semiconductor device fabrications, alternative semiconductor materials have been developed, simply synthesized in the form of colloidal solutions containing tiny, nanometer sized semiconductor particles. These solutions not only allow processing of optoelectronic devices by technologies as simple as ink-jet printing, but devices made with them exhibit even advantages as compared to those fabricated by standard technologies. Thus semiconductor nanoparticles, so called quantum dots, are implemented for instance in a new generation of TV-sets with superior color-performance, to generate the red and green light. The same materials are widely used as fluorescence markers in bio-medical applications to monitor reactions in cells or to uncover tumors and are applied to provide to the dazzling white of light emitting diode based light bulbs a warmer shade. Such colloidal solution based devices, operating in the visible spectral region are ready-available on the market since recent years. Even more promising are, however, devices and applications based on colloidal materials operating in the infrared spectral region, because the omnipresent Si based technology fails to work at long wavelength, and other conventional inorganic semiconductor devices are usually substantially more expensive. Infrared imaging, molecule spectroscopy, fluorescence labeling in the infrared, optical communication, and quantum information processing are potential fields of applications which could be covered by novel solution processed materials and devices.

Approach

Photonic Materials are typically comprised of half-wavelength or even nanoscopic components which are artificially assembled to render a photonic circuit or a tailor-made material, often called "meta"-material, the Greek prefix "meta" meaning materials which go "beyond" the naturally occurring materials with all their limitations (diffraction limited, void of magnetic response, with optical parameters dictated by the optical band gap of the bulk material etc.). Hence, we can subdivide the approach to photonic materials in three categories: (i) The search for nanoscopic photonic building blocks whereby the nanoscopic (deep sub-wavelength) geometry leads to optical characteristics not achievable with the macroscopic materials. Such building blocks are also called "artificial atoms". (ii) The interconnect between single building blocks in order to form photonic circuits (including the challenge of interfacing to classical electronic circuits). And (iii), the composition of quasi-homogeneous materials comprising artificial atoms.

Challenge (i) includes the search for artificial electric atoms which are apt to modify the dielectric function of an optical material and magnetic atoms which may modify the magnetic permeability, the latter one being a largely untapped field of research and applications, a fact that manifests itself by the observation that most textbooks on optics claim that the relative magnetic permeability is set to 1 throughout the book. Both, **electric and magnetic artificial atoms** can be comprised by (noble) **metallic nanostructures.**

Another important class of artificial atoms are **semiconductor quantum dots**. They are either **grown on solid substrates** (at JKU predominantly on the basis of Si and Ge or on (Ga,In,Al)As basis [1]), or produced by **wet-chemical or by organo-metallic synthesis** routes (at JKU first of all infrared emitting materials such as lead-chalcogenides,[2], silver-salts, or chalcopyrits). With decreasing size, the band gap of the bulk material becomes less and less important. If both, electrons and holes are strongly confined (i.e. the diameter of the dots is less than the excitonic Bohr radius), the optical transitions in absorption and emission are determined by electronic levels similar to the orbitals in real atoms. Thus, quantum optical effects like single and entangled photon emission on demand become accessible and can be exploited in solid state systems compatible with optoelectronic processing. These materials usually exhibit superb optical properties in respect to the extinction of light and photon emission quantum yields. Challenging is, however, to apply them in electro-optical devices, because the colloidal quantum dots are usually covered by insulating organic and inorganic shells, preventing any current flow in films of colloidal quantum dots. Thus, many efforts are currently performed to replace the insulating protective shells by electrically conducting ones. Inorganic complexes or inorganic/organic hybrids are favored as shell materials which do not only cover the quantum dots, but also transform into a semiconducting matrix upon mild thermal treatment. These matrices also improve the stability of solution processed devices, making them more similar to conventional inorganic semiconductors, however, fabricated by cheap and simple technologies. One important concern of these solution processed opto-electronic materials and devices is their potential toxicity. That's why we focus our interest on more environmental benign materials as a future replacement of the currently more favored colloidal quantum materials, containing various heavy metals.

Active building blocks (i.e. building blocks comprising absorption and emission lines) alternative to semiconductor quantum dots are tailor-made organic molecules such as **π-conjugated dye molecules or color centers in solids**. A promising example for the latter are nitrogen-vacancy color centers in nanoscopic diamonds which hold promise for quantum-optical applications, specifically as "photon on demand" single photon emitters. One of the big challenges for organic active elements is the stability against environmental influences (specifically to prevent bleaching by photooxidation).

Challenge (ii) involves **interconnects** between (nano-)photonic elements themselves and between the photonic elements and classical electronic circuits. Active photonic elements may, for example, be used as nanoscopic light sources. Sub-diffraction light guides may be used for on-chip transfer of information and a nanoscopic photo-detector might be used to record the signal. At some point, interface to the classical electronics-based world is (still) necessary. Active elements as discussed in (i) might be used as sources and detectors of photons (semiconductor quantum dots, color centers, organic molecules). **Sub-wavelength scale transport of photons** may well be realized with wave guides which contain some sort of metals which allow for sub-diffraction confinement of electromagnetic waves on the one hand but show only little absorption (small imaginary part of materials functions) and little kinetic inductance on the other hand. Substantial basic research is necessary in these fields.

In **challenge (iii)**, sub-wavelength materials need to be assembled (bottom up) or structured (top down). Structuring on the slight-sub-wavelength range leads, for example, to **photonic crystal structures** and allows a control of the interaction strength between photons and matter [3]. Further miniaturization leads to **metamaterials**. Composite materials might, for instance, be used as mirror-less lasing structures. In a normal laser, an active medium is placed in between at least two reflecting surfaces. As an alternative, a photonic crystal may host active material and give rise to lasing via distributed feed-back rather than repeated reflection between two mirrors. While a photonic crystal is still a periodic structure, one can also achieve stimulated emission and even lasing with randomly distributed scatterers. In this case, active artificial atoms (such as semiconductor quantum dots) and scattering nanoparticles might be randomly mixed into some carrying matrix. Ultimately, one tries to achieve nanoscopic sources of coherent optical radiation by using a single metallic **nanoparticle as a resonator**, surrounded or embedded in active materials [4].
Other examples of metamaterials include materials with negative index or "hyperbolic materials" which are bi-refringent materials where the dielectric constant along one of the optical axes is positive and along the other axis it is negative. Such a material would act like a dielectric for one polarization and like a metal for the other polarization. Resolution beyond the diffraction limit can be achieved with "lenses" made out of such a material. Principally thinkable are also materials, which show high nonlinearities along one optical axis but behave linear along the other axes. Nonlinearity is the basis of any bi-stable switching device.

Beyond the aim of constructing photonic materials, i.e. materials where the usability for photonic applications is in the focus of interest, photonics can in turn provide ample of tools to **(nano-)structure materials (specifically the surfaces thereof)** which might then be used in totally different areas of research, technology, or production. Laser-inscribing of surfaces is one example. Optical surface-modification is another one. Specifically, photonic techniques can be used in production to render surfaces hydrophilic or hydrophobic or to increase or decrease friction. Also, optical properties of surfaces can be changed by photonic means and render surfaces, for instance, more or less reflecting. Another growing field of research and application is the interaction of biological cells with sub-wavelengths photonic nanostructures. On one hand, it becomes more and more obvious that nanostructures with dimensions of 100 nm and below can strongly influence cells in contact with these structures: nanostructures seem for instance to be able to activate the differentiation of stem cells into various mature cell types. On the other hand, optical readout is state of the art in high-resolution microscopy in cell biology or high-throughput medical assessment and light is used in cell specific cancer therapies.

Impact

The focus of our current research lies in the **expansion of our fundamental understanding** of components for photonic materials such as semiconductor quantum dots or metallic nanoparticles. We expect to gain further knowledge specifically in the field of the photonic interactions of building blocks made out of totally different materials in order to construct novel materials properties which exceed the sum of the properties of the individual components by far. Further, we would like to push three-dimensional two photon lithography to its nanoscopic limits [5].

Industrial impact, also on a relatively short time frame, is expected in photonic modifications of materials, specifically in the range of surface modification. Applied research and development will lead to novel materials and substrates for biological applications. One example would be a specific surface modification of the inside walls of microfluidic cells in bio-reactors suitable for cell culture. Also the direct combination of plasmonic nanomaterials with biological cells and tissues offers large future potentials in the field of tissue engineering, cell therapies and advanced medical diagnostics [6]. Another example are infrared-cameras processed from colloidal solutions, which are potentially low cost and mass-producible, since they are based on semi-manufactured products from liquid crystal display screens. The foreseeable transition from electrical to optical data transmission also within the CPU of future computers offers huge opportunities for companies specialized on photonic technologies.

Large **societal impact is** expected from the use of novel photonic materials in bio-medical technology on the one hand [7], and for the application of photonic materials in energy efficient lightning or energy conversion devices on the otherhand.

References

[1] Y.Huo et al.: "A light-hole exciton in a quantum dot", Nature Physics 10, 46, 2014. M. Grydlik, G. Langer, T. Fromherz, F. Schäffler, M. Brehm, "Recipes for the fabrication of strictly ordered Ge islands on pit-patterned Si(001) substrates", Nanotechnology 24, 105601 2013.

[2] S. Z. Bisri, C. Piliego, M. Yarema, W. Heiss and M. A. Loi: "Low driving voltage and high mobility ambipolar field-effect transistors with PbS colloidal nanocrystals" Adv. Mat., Vol. 25, pp. 4309-4314, 2013.

[3] M. Humer, R. Guider, F. Hackl and T. Fromherz: "Polymer-embedded colloidal lead-sulfide nanocrystals integrated to vertically slotted silicon-based ring resonators for telecom applications", J. Nanophotonics Vol. 7, 073076, 2013.

[4] T.A. Klar: "Metal Nanostructures and Active Materials", in O. Fesenko, L. Yatsenko and M. Brodin (eds.): "Nanomaterials Imaging Techniques, Surface Studies, and Applications", Springer, 2013.

[5] R. Wollhofen, J. Katzmann, C. Hrelescu, J. Jacak and T.A. Klar: "120 nm resolution and 55 nm structure size in STED-lithography", Optics Express, Vol. 21, No. 9, 10831-10840, 2013.

[6] R.-A. Barb, C. Hrelescu, L. Dong, J. Heitz, J. Siegel, P. Slepicka, V. Vosmanska, V. Svorcik, B. Magnus, R. Marksteiner, M. Schernthaner and K. Groschner "Laser-Induced Periodic Surface Structures on Polymers for Formation of Gold Nanowires and Activation of Human Cells" Applied Physics A, published online DOI 10.1007/s00339-013-8219-9, 2014.

[7] M. Wiesbauer, R. Wollhofen, B. Vasic, K. Schilcher, J. Jacak and T. A. Klar: "Nano-Anchors with Single Protein Capacity Produced with STED Lithography ", Nano Lett., Vol. 13, No. 11, 5672–5678, 2013.

Competencies

Our work on Photonic Materials is interlinked with national and international research projects and consortia, including the platform “Photonik Austria”.

Some of the current research projects include:

- Active and Low Loss Nano Photonics
(ERC Starting Grant ActiveNP, Prof. Klar, IAP)
- 3D Scaffolds Carrying Protein Nano Anchors
(FWF, Prof. Klar, IAP, closely related to the DFG Priortiy programme 1327: Optical sub 100 nm lithography)
- SolarTrap: Manipulation and modification of sunlight in organic solar cells (FFG / Klimafonds, Dr. Hrelescu, IAP)
- Infrared Optical Nanostructures (IRON) (FWF, SFB, Prof. Schäffler, Prof. Stangl, Prof. Heiss, a.Prof. Fromherz, HFP)
- Processing Light - Advanced Technologies for Optical Nanostructures (PLATON) (FFG, a.Prof. Fromherz, HFP)
- Nanoimprint Lithography in Austria:
enabling emerging high added value applications (NILAustria) (FFG, a.Prof. Fromherz, HFP)
- Hybrid artificial and natural atomic systems
(EU / Prof. Rastelli, HFP)
- 3DCellStretch “Three-dimensional stretchable polymer scaffolds for mechanical stimulation of cells”
(FFG, a.o. Prof. Heitz, IAP)

Instrumentation to characterize photonic materials include:

- Optical microscopy (bright field, dark field, fluorescence)
- Various types of laser sources
(continuous wave and pulsed from nano- to femtosecond)
- UV-Vis and Fourier transform extinction spectroscopy
- Dark-Field spectroscopy
- Multiple color femtosecond pump-probe setups
(100 kHz Ti:Sa amplifier pumping two OPAs)
- Time correlated single photon counting and superconducting single-photon counters
- Several micro-photoluminescence and micro-electroluminescence setups
- Equipment to prepare small scale photonic materials (evaporation, sputtering, pulsed laser deposition, sintering, spin coating, wet synthesis of noble metal and semiconductor nanoparticles, molecular beam epitaxy, electron beam lithography, nano imprint lithography)
- Spectroscopic ellipsometry for determining the real and imaginary refractive index (NIR-VIS-UV, laboratory based)
- Raman spectroscopy for chemical analysis
(laboratory based)
- UV excimer lasers and lamps for nanostructure formation at polymer surfaces

Proponents

Univ.-Prof. Dr. Thomas Klar
Institute of Applied Physics (IAP)

thomas.klar@jku.at
http://www.jku.at/applphys/

Univ. Prof. Dr. Armando Rastelli
Institute of Semiconductor and Solid State Physics

armando.rastelli@jku.at
http://www.jku.at/hfp/

Keywords

Photonic Crystals, Semiconductor Nano Crystals, Noble Metal Nanoparticles, Silicon and Silicon/Germanium Photonics, Active Photonic Materials, Nanostructures for Optical Biosensing, 3D Optical Nanolithography, Integrated Optics, Single Photon and Entangled Photon Sources, Strain-Tunable Optoelectronics, Nanocrystals for Infrared Photonics, Interaction of Biological Cells with Photonic Materials

Soft Active Materials

"Without much doubt, the future of soft materials research is bright, and this century may later be termed 'the soft matter age'."

Siegfried Bauer

Focus Line 1:

Smart(er) Materials for Products and Production

Coordinator:

Univ.-Prof. Dr. Siegfried Bauer
Institute of Experimental Physics,
Soft Matter Physics Department

sbauer@jku.at
http://www.jku.at/iep

Research Focus

- Soft Materials, Strechable Electronics
- Soft Energy Generators
- Electronic Skins
- Complex Bionic Systems

Vision

We are surrounded by soft matter; soft materials impart the life of animals and plants and also create exciting opportunities for new discoveries, inventions and products which significantly will change our life, due to their unique properties, inimitable with solid materials. Take a look at human beings from a technological perspective. We have a brain, while unable to match in terms of computation with the speed of current microcomputers, the brain is an extremely energy efficient and adaptable computation system. We have hands, an amazing example of a soft robotic system, of course unable to match the precision and high torque of motors, our hands nevertheless easily allow us to manipulate objects. Imagine human skin – a great example of a mechanically stretchable, self-healing large area electronic circuit, sensitive to pain, touch, temperature changes, humidity and many other environmental stimuli. We generate and store energy to power our biological system, and finally, at the end of our service life, we are degraded in an environmentally friendly manner. The multifunctional biological model "human being" is inspiring the development of technical equivalents – referred to as "**soft robots**", "**electronic skin**" and "**soft energy generators**". Inspired by the "machine-human" in the science-fiction movie Metropolis, or by the sentient android Data in Star Trek, engineers and materials scientists are dreaming to mimic nature for creating a world of **engineered soft matter devices**. Electronic devices are an example of the rapid changes we are currently envisioning, they advance from heavy, bulky devices to smart, mobile appliances, and all of us carry phones, watches, and glasses. Nevertheless, our smart appliances of today are still rigid, precluding them from being intimately integrated into daily life, for example on textiles, directly on skin or even within our body. Current trends in research on ultraflexible and stretchable electronics directly address the technological challenge of "**electronics anywhere**". Flexible, stretchable and textile electronics are currently emerging research areas that may develop into mainstream technologies. Pushing boundaries further than ever before to make electronics both virtually unbreakable and imperceptible describes the vision of "electronics anywhere". We will get used to the idea that common materials like flexible cellular polymers, stretchable dielectric elastomers, and ultracompliant elastomeric gels, which are today seen only in passive applications, like in thermal insulation, car tires, bicycle seats etc., will become the materials base of future smart electronic appliances.

This vision statement proposes research on the materials base and on the production technologies for soft robots, stretchable electronics and soft energy generators, changing paradigms in our thinking of technical systems as rigid and bulky devices. Cross-disciplinary materials related research will be strongly coupled to the development of process and manufacturing technologies, enabling recyclable or degradable truly complex **bionic systems**, eventually similar to the android "Data", the visionary character from Star Trek. Without much doubt, the future of soft materials research is bright, and **this century may later be termed "the soft matter age"**.

Approach

Soft robots, stretchable electronics and soft energy generators are research fields that are rapidly growing on an accelerated pace. A quick glance of the topics in ISI Web of Knowledge shows that all three areas show a remarkable growth in publications per year and in number of citations per year, showing the potential materials scientists and engineers see in these topics. This is also strongly underlined by invited review articles celebrating the 25th anniversary of the journal "Advanced Materials" [1-3]. Artificial muscles provide an example of the fast adaptation of an emerging technology from laboratory curiosity to real products [4,5]. Electronic skin is at the transition from simple laboratory demonstration to applications on robots and human skin [6].

The main objective in the research of soft active materials is to address and solve fundamental questions on materials properties and combinations to advance soft robots, stretchable electronics and soft energy generation. The core activity in this research must be on basic science, with potential applications in the design of bionic systems, for example unbreakable and imperceptible electronic skin. Soft and hard materials and the combination of those in unprecedented ways will be at the heart of the investigations. Mechanical material properties and mechanical modelling of soft robots, stretchable electronic devices and soft energy generators will form the core of the activities, accompanied by interdisciplinary research between groups in physics, chemistry, mechanical and electrical engineering, polymer technology and computer science. We assume that these combined efforts of a large group of research teams from different fields will create a substantial and critical mass to develop JKU into a world leading place of bionic research. The proposed work aims at stretching soft materials performance to new grounds – both in applications as well as in exploring basic science issues behind.

The range of activities in the focus line on smart materials will be necessarily extremely wide and diverse, but there will be clear common bracket in all of the works, the use of entropy elastic soft and ultrasoft materials in combination with a wide range of other materials, from liquids to gels, and from polymers to solids in thin film, micro- or nanostructured forms. The anticipated work is obviously interdisciplinary and requires expertise in the thermodynamics of soft materials, in the continuum mechanics of energy and entropy elastic materials under extreme conditions, in chemical synthesis, in electrical and device engineering, as well as in the fast and practical implementation of basic research results into technical appliances. The combined efforts of the different teams from different scientific disciplines available at JKU make such a wide and diverse research effort possible.

JKU is internationally known for many first scientific achievements, including electrically controlled, self-sensing soft robots, capable of complex motion in 3d space, low voltage organic flash memories, edible electronics, nature inspired hydrogen bonded organic semiconductors, stretchable batteries, printed sensors, active matrices and displays with a minimum number of inks, ultralight solar cells and polymer light emitting diodes as well as imperceptible electronics which can be crumpled like a piece of paper [7-10].

Impact

In the **Soft Robots** field, the research is expected to create **scientific impact** in understanding the fundamental principles of actuators with giant and fast electrically triggered and controlled deformation. We expect to be able to show soft robots with a capability to be highly resistant to mechanical damage, to self-heal, and to actuate rapidly. In the **Imperceptible Electronics** field, we expect to create novel applications in displays, in sensors, thermal imaging, in sports and recreation, medical treatment and prosthetics, electronic skin, robots and consumer electronics. In the **Soft Energy Generation** field, we expect to create significant interest in the design of unconventional **energy conversion systems on large and small scales**, from the energy of human gait to the huge and untapped source of energy from ocean waves.

There is a huge potential of the research to open up **industrial** and **commercial** opportunities from the founding of spin-of companies that may develop into mainstream technologies to the fast and efficient transfer of knowledge to big players.

There are also countless potential **societal impacts**, for example a low-cost, energy efficient and environmentally friendly design of products. Ultimately the research will lead to an intimate integration of technology into our daily life, where the integration will not be felt dangerous due to the imperceptible and well adapted nature of the products to human beings. We are close to demonstrate technologies forecasted in science fiction to the 24th century, looking at the speed of new developments in all of these areas envisioned there is no doubt that there will be rapid progress towards fully integrated bionic systems in the future, letting us forecast the 21st century as the beginning of the soft matter age.

References

[1] M. L. Hammock, A. Chortos, B. C.-K. Tee, J. B.-H. Tok and Z. Bao: “25th anniversary article: The evolution of electronic skin (E-Skin): A brief history, design considerations, and recent progress”, Adv. Mater. Vol. 25, 5997, 2013.

[2] E. D. Glowqcki, G. Voss and S. Sariciftci: “25th anniversary article: Progress in chemistry and applications of functional indigos for organic electronics”, Adv. Mater. Vol. 25, 6783, 2013.

[3] S. Bauer, S. Bauer-Gogonea, I. Graz, M. Kaltenbrunner, C. Keplinger and R. Schwödiauer: “25th anniversary article: A soft future: From robots and sensor skin to energy harvesters”, Adv. Mater. Vol. 26, 149, 2014.

[4] R. Pelrine, R. Kornbluh, Q. Pei and J. Joseph: “High-speed electrically actuated elastomers with strain greater than 100%”, Science Vol. 287, 836, 2000.

[5] F. Carpi, S. Bauer and D. DeRossi: “Stretching dielectric elastomer performance”, Science Vol. 330, pp. 1759-1761, 2010.
[6] S. Bauer: “Sophisticated skin”, Nature Mater., news & views, Vol. 12, pp. 871-872, 2013.

[7] T. Sekitani, T. Yokota, U. Zschieschang, H. Klauk, S. Bauer, M. Takamiya, T. Sakurai and T. Someya: “Organic flash memory transistors for flexible intelligent sensor arrays”, Science, Vol. 326, pp. 1516-1518, 2009.

[8] M. Kaltenbrunner, M. S. White, E. D. Głowacki, T. Sekitani, T. Someya, N. S. Sariciftci and S. Bauer: “Ultrathin, and lightweight organic solar cells with high flexibility”, Nat. Commun., Vol. 3, 770, 2012.

[9] M. S. White, M. Kaltenbrunner, E. D. Głowacki, K. Gutnichenko, G. Kettlgruber, I. Graz, S. Aazou, C. Ulbricht, D. A. M. Egbe, M. C. Miron, Z. Major, M. C. Scharber, T. Sekitani, T. Someya, S. Bauer and N. S. Sariciftci: “Ultrathin, highly flexible and stretchable PLEDs”, Nature Photon., Vol. 7, pp. 811-816, 2013.

[10] M. Kaltenbrunner, T. Sekitani, J. T. Reeder, T. Yokota, K. Kuribara, T. Tokuhara, M. Drack, R. Schwödiauer, I. Graz, S. Bauer-Gogonea, S. Bauer and T. Someya: “An ultra-lightweight design for imperceptible plastic electronics”, Nature, Vol. 499, pp. 458-463, 2013.

Competencies

The operational research units at JKU in Physics, Chemistry, and Engineering are all very well positioned in the international research communities, ranging from nationally funded projects by the FWF and the FFG to EU funded projects within FP7. Examples of the high standings of the research groups are demonstrated with an ERC Advanced Grant at the Soft Matter Physics department and a Wittgenstein award at the Linz Institute of Organic Solar Cells. Siegfried Bauer has also been elected to serve on an ERC starting grant panel in 2014.

The Departments and Institutes involved in the work run outstanding, state of the art laboratory equipment and experimental infrastructures, to synthesize materials, to test their mechanical, thermal, electrical and optical properties, and to develop rapid prototype and production technologies.

Proponent

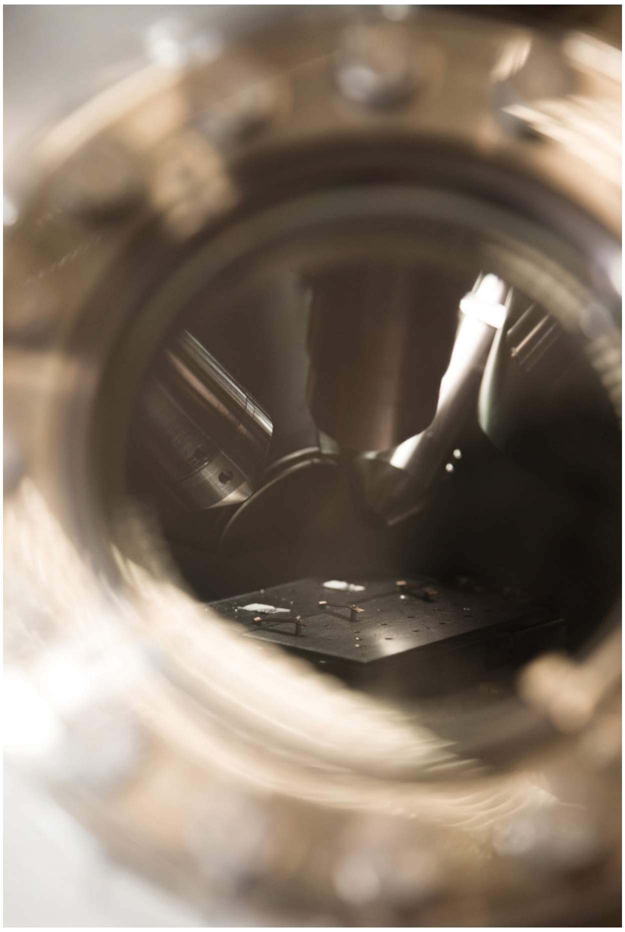
Univ.-Prof. Mag. Dr. Siegfried Bauer
Institute of Experimental Physics,
Soft Matter Physics Department

sbauer@jku.at
http://www.jku.at/iep

Keywords

Ultraflexible Electronics, Stretchable Electronics, Actuators, Energy Harvesting, Dielectrics, Piezoelectrics, Organic Semiconductors

Materials Science and Analysis



"Smarter production processes and the fabrication of smart products require advanced Materials Analysis for fast and comprehensive investigation of all relevant materials at all steps in the production chain."

Johannes Pedarnig

Focus Line 1:

Smart(er) Materials for Products and Production

Coordinator:

Univ.-Prof. DI Dr. Kurt Hingerl
Center for Surface and Nanoanalytics (CSNA-ZONA)

kurt.hingerl@jku.at
http://www.jku.at/zona/content

Research Focus

- Fundamental Properties of Materials and Interfaces by Bridging Atomistic, Nano- and Microstructure Levels
- Advanced Analysis Techniques and Theoretical Models of the Behaviour of Materials and Interfaces
- In-situ, In-process Compatible (e.g. optical, X-ray) Analysis Techniques

Vision

Materials Science plays a pivotal role for modern industrial products and processes. It helps to develop new energy generation technologies, more resistant hard coatings, custom designed sensors for a specific interaction with environmental parameters, and also more energy efficient devices, all of them supposed to be easily recyclable and less toxic. Examples are fuel cells, advanced steels, hybride materials synthesis, wafer surfaces, corrosion and tribological coatings. The Centre for Surface and Nanoanalytics (CSNA) acts as a mediator between basic research and applied material science, serving both the in house (JKU) institutes as well as cooperating interested Austrian and European companies. It plays a primary role through support of interdisciplinary and interfacultary research, training and education. It further provides in one unit essential resources for electron- and ion beam characterization of materials, for determining optical properties, for micro- and nano-characterization, through specific analysis techniques for surfaces and interfaces.

Smarter production processes and the fabrication of smart products require advanced Materials Analysis for fast and comprehensive investigation of all relevant materials at all steps in the production chain. The measurement and monitoring of the chemical composition of raw materials, additives, chemical agents, intermediate substances, by-products, and the final material and product are key points in smarter industrial processing and essential to strengthen European competitiveness [1]. This holds for many industrial branches, for example metallurgy, polymer technology, electronics, chemistry, construction and building, recycling, etc [e.g., 2, 3]. The Institute of Applied Physics (IAP) is performing scientific research on the development and application of novel laser-based techniques. The current topics of research are: (i) Optical sensing for chemical element analysis, (ii) Nanophotonics and metamaterials, (iii) Laser-matter interaction processes (thin films, surface modifications). This includes measurements in the laboratory, modeling and simulations, and also field measurements, for instance in industrial environment on site at production plants.

Approach

The aim of the Materials Science task is to understand the Physics and Chemistry, i.e. the underlying function: we put great emphasis placed on fundamental properties of materials, surfaces and interfaces rather than on applied science and product development. Naturally, application of materials is the ultimate goal, but this needs to be built on firm theoretical basis so that improvements can be made more efficiently and reliably. Particular attention is therefore given to understanding a material's behaviour from the atomic/nano-level via microstructure to macrostructure levels using advanced analytical techniques and computer modelling. This strategy is applied to both the improvement of conventional "bulk" materials, such as steel, and to new functional materials for increasingly smaller, "smarter" devices", e.g. MEMS.

The aim of the Materials Analysis task is to develop laser-based measurement techniques for compositional analysis of "technical materials". The interaction of intense laser radiation with the relevant materials and the optical response of samples (e.g. the emission of laser-induced plasma, LIBS) are studied to develop measurement systems for fast and accurate analysis without time-consuming preparation. The LIBS method can be applied to materials in form of solids, liquids, gases, powders, etc. Multi-component materials are quantitatively analyzed by calibration-based and calibration-free methods (trace/minor and major elements) in the laboratory and on-site / in-line / at-line in industrial environment [4, 5].

The Materials Science and Analysis work is performed in national and international research projects and in co-operation with various industrial partners from different branches (e.g., Austrian industries such as OMV, voestalpine Stahl, EVG, Kraiburg Austria, AVE Österreich) and with innovative start-ups (SMEs). Our partners provide scientific and technical challenges to our specific blend of competences, facilities, and we contribute with our research approaches in strategic national/ international R&D partnership activities.

Impact

With our Materials Science and Analysis activities we are addressing scientific and technological issues as well as societal needs. We are aiming for a detailed understanding of all physical and chemical processes relevant for the development, fabrication, optimization, and production of novel, functional high-value materials. Besides fundamental scientific investigations we are aiming also for technological advancements to cope with the requirements for different industrial applications, e.g. the development and integration of sensing systems. We expect our RTD activities to contribute to the development of novel tailor-made materials, the optimization and production of high-tech materials, the in-line process monitoring etc and to have significant impact in various branches such as metal, chemical, and polymer industries. Furthermore, large societal impact is reached by the education and training of young scientists on modern topics that are relevant for our industries. This includes scientific and technological topics and conjunct topics such as resource-efficient production processes and sustainability.

References

[1] Euler Hermes Economic Research Department: "The Reindustrialization of the United States (Special Report), Economic Outlook no. 1187, 2012. Available: http://www.eulerhermes.us/economic-research/economic-publications/Documents/economic_outlook_1187.pdf.

[2] C. Hagelüken and C.E.M. Meskers: "Mining our computers – opportunities and challenges to recover scarce and valuable metals from end-of-life electronic devices", in H. Reichl, N.F. Nissen, J. Müller and O. Deubzer (eds.): Electronics Goes Green 2008+, Stuttgart, Fraunhofer IRB Verlag, pp. 623-628, 2008.

[3] McKinsey & Company: "Towards the Circular Economy: Economic and business rationale for an accelerated transition", The Ellen MacArthur Foundation, 2012. Available: http://www.ellenmacarthurfoundation.org/.

[4] N. Huber, S. Eschlböck-Fuchs, H. Scherndl, A. Freimund, J. Heitz and J.D. Pedarnig: "In-line measurements of chlorine containing polymers in an industrial waste sorting plant by laser-induced breakdown spectroscopy", Applied Surface Science, Vol. 302, pp. 280–285, 2014.

[5] J.D. Pedarnig, P. Kolmhofer, N. Huber, B. Praher, J. Heitz and R. Rössler: "Element analysis of complex materials by calibration-free laser-induced breakdown spectroscopy", Applied Physics A, Vol. 112, No. 1, pp. 105-111, 2013.

[6] D. Stifter: "Beyond biomedicine: a review of alternative applications and developments for optical coherence tomography", Applied Physics B, Vol. 88, No. 3, pp. 337-357, 2007.

[7] M. Arndt, J. Duchoslav, H. Itani, G. Hesser, C.K. Riener, G. Angeli, K. Preis, D. Stifter and K. Hingerl: "Nanoscale analysis of surface oxides on ZnMgAl hot-dip-coated steel sheets", Analytical and Bioanalytical Chemistry, Vol. 403, No. 3, pp. 651-661, 2012.

Competencies

Besides skilled and creative scientists, the analytical facilities available at ZONA and IAP include:

- SEM/EDX - Scanning Electron Microscopy/Energy-dispersive X-ray spectroscopy
- FIB/SEM - Focused Ion Beam/Scanning Electron Microscopy
- TEM- Transmission Electron Microscopy
- FT-IR - Fourier Transform-InfraRed spectroscopy
- XPS - X-ray Photoelectron Spectroscopy
- AES – High Resolution Auger Spectroscopy
- IoIm - Ion Implantation for Doping and Surface Modification
- XRD – x-ray diffraction system (3 circle) for structural analysis of solid materials
- AFM – atomic force microscopy
- TG – Thermogravimetry
- OM – Optical microscopy (bright field, dark field, fluorescence)
- Various types of laser sources (continuous wave and pulsed from nano- to femtosecond) and spectrometers
- Materials synthesis equipment (incl. evaporation, sputtering, laser deposition, sintering, spin coating)

In addition, the following techniques are especially useful for optimizing and monitoring processes in situ and in real time, e.g. in production processes:

- SE- Spectroscopic Ellipsometry for determining the real and imaginary refractive index (NIR-VIS-UV, labor. based)
- IR-SE Infrared Spectroscopic Ellipsometry for chemical analysis (laboratory based)
- Raman Spectroscopy for chemical analysis (laboratory based)
- LIBS – Laser-Induced Breakdown Spectroscopy: Mobile and transportable systems for element analysis out-of-labor
- Full-field Optical Coherence Microscopy

All these analytical techniques are accompanied with our expertise down to the shop floor, through consultancy for process monitoring [6-7]. Further analysis techniques are available in cooperation with Chemistry Institutes of JKU Linz.

Proponents

Univ.-Prof. DI Dr. Kurt Hingerl
Center for Surface and Nanoanalytics (CSNA-ZONA)

kurt.hingerl@jku.at
http://www.jku.at/zona/content

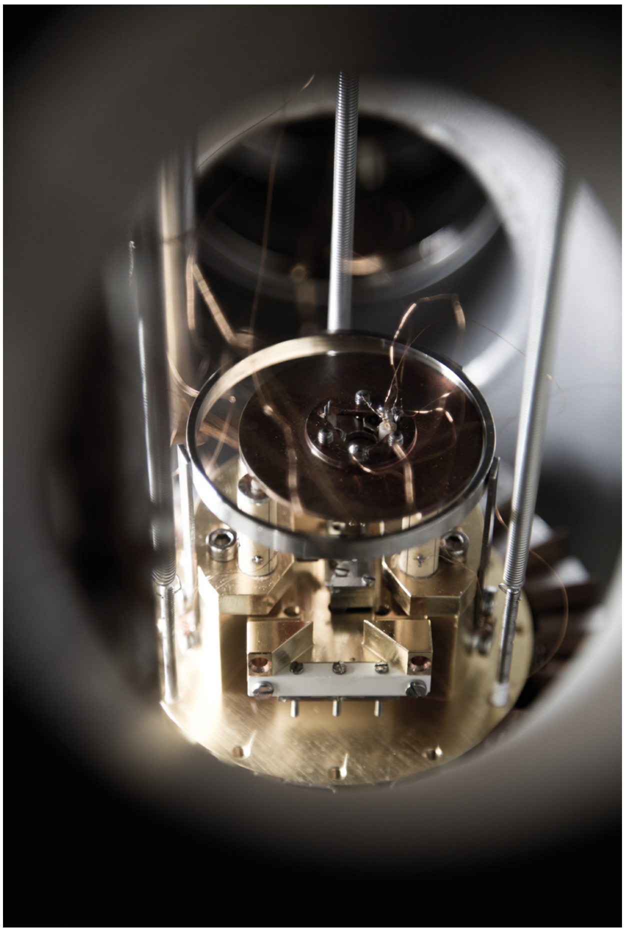
A.Univ.-Prof. Mag. Dr. Johannes D. Pedarnig
Institute of Applied Physics (IAP)

johannes.pedarnig@jku.at
http://www.jku.at/applphys/

Keywords

Material Science for Current Production Environments, Physics and Chemistry for High Tech Devices- From Structure to Function, Advanced Materials, Materials Synthesis, Sensors, Surface and Nanoanalytics, Compositional Analysis of Complex Industrial Materials, In-situ / In-line / At-line / On-line Process Monitoring.

Nanostructured Quantum-Electronic, Optic, Magnetic and Spintronic Materials



"Further progress in the field of information processing and communication is tightly linked to the development of new material combinations and device concepts. As device sizes keep shrinking new challenges and opportunities open up."

Armando Rastelli

Focus Line 1:

Smart(er) Materials for Products and Production

Coordinator:

Univ. Prof. Dr. Armando Rastelli
Institute of Semiconductor and Solid State Physics
Semiconductor Physics Division

armando.rastelli@jku.at
http://www.jku.at/hfp

Research Focus

- Fabrication of Low-dimensional Semiconducting and/or Magnetic Heterostructures
- Fabrication of Nanostructured Devices and Demonstrators in the Cleanroom
- Structural, Electronic, Optic, Magnetic and Spintroni Characterization of Fabricated Materials and Devices
- Simulations of Structural and Quantum Mechanical Properties of Materials and Nanostructures
- Device Fabrication on a Demonstrator Level

Vision

With state-of-the-art (2014) microprocessors, the semiconductor industry has realized monolithically integrated computer chips with 1.4 billion transistors fabricated in a 22 nm process. The Tri-Gate transistors have a fin-width of 8 nm and employ strained silicon technology as well as high-k dielectrics and metal gates. All these technological and materials-science achievements would not have been possible just ten years ago. They were introduced in pursuit of Moore's law, which has accurately predicted the exponential shrinkage of the critical dimensions in semiconductor devices for meanwhile more than 40 years.

Back in 2003, microprocessors and memory chips were among the first industrial products fabricated in a true nanotechnology, i.e. critical dimensions in all three directions of space became smaller than 100 nm. The fabrication process of such devices follows a top-down concept, i.e. the nano-scale features are fabricated in a deterministic way by employing well-defined masks and related structuring techniques for the realization of the active and passive components.

Besides computer chips based on the ubiquitous semiconductor silicon, many other material- and technology routes have been developed in the last years, mainly for applications in the field of information processing, but also regarding efficient energy conversion techniques and every-day lighting solutions. Cost efficient magnetic data storage, optical high-speed fiber communication, nanostructured materials for thermoelectric applications and various building blocks for quantum computing are just a few examples. Several of them employ new bottom-up concepts, which lead to functional nanostructures based on self-organization phenomena. These can, for example, be self-assembled nanofeatures with novel electronic, optical and spintronic properties that develop at surfaces or interfaces during heteroepitaxial crystal growth, or chemically synthesized nanocrystals with similar properties. In this way, a cost effective fabrication of low-dimensional structures becomes feasible, which provides access to outstanding physical properties that are suited for a wide variety of applications in the field of information technology.

Of particular interest is a combination of top-down and bottom-up approaches, which results in new functionalities on the nanoscale that are still addressable in a similar way as, for instance, the transistors in a microprocessor or a memory chip. Examples comprise coherent arrays of quantum-dot light emitters, confined spins in quantum dots as building blocks for quantum computers, arrays of extremely small magnetic memory cells and many more.
The development of novel concepts based on nanoscale phenomena requires highly interdisciplinary approaches. Evidently, materials sciences play an important role, as do the technologies to define and address features on the nanoscale. To characterize the resulting nanostructures, a broad range of analytical tools is required that allows their chemical, structural, electronic, optical and spintronic characterization on lengths scales down to the atomic level. Modelling of the nanostructures is as important, because on the nanoscale the physical and chemical properties of matter become dominated by quantum mechanical effects.

Based on this background, and the expected impact on the industrial production, nanoscience and -technology has been recognized by all major industrial nations as a key area for the development of the economies and societies in the 21st century. This led to large international and national programs aiming toward the formation of interdisciplinary centers of excellence in this field, and subsequently to the exploitation of the results in the industrial production. Simultaneously, interdisciplinary education in the field of nanoscience and -technology is being fostered worldwide, for instance by the implementation of dedicated undergraduate and graduate courses at universities.

Approach

The research efforts at the Institute of Semiconductor and Solid State Physics cover a wide range of the aforementioned nanoscale activities in the fields of information technology and energy conversion. These activities can be subdivided in five topical fields, namely Materials Science, Nanotechnology, Nanoanalytics, Simulations and Devices. To cover these fields in a comprehensive and, on an international level, competitive manner, substantial investments in the infrastructure of the institute have been made over the last 25 years. For example, the institute operates a cleanroom with all installations necessary for the synthesis of various novel materials and for processing them into nanodevices on a demonstrator level. A broad complement of analytical tools is available to characterize the structural, electronic, optical and magnetic properties of the materials and devices on the nanoscale, and to assess their application potential. Because of the novelty of the approaches, many investigations are on a basic research level aiming for a deeper understanding and control of quantum mechanical effects, but there are always application-driven long-term goals involved, in particular in the fields of advanced light sources and detectors, thermoelectric materials, magnetic semiconductors and spintronic functionalities. In the following, a brief account of the main activities at the Institute of Semiconductor and Solid State Physics is given for the aforementioned topical fields.

(i) Materials Science
The institute uses several techniques to fabricate semiconducting and magnetic heterostructures and composites. On a laboratory scale, the most versatile technique is molecular beam epitaxy (MBE). MBE utilizes atomic or molecular beams in an ultra-high vacuum environment. These are directed onto a heated, single crystalline substrate that defines the lattice structure of the deposited film. In this way, epitaxial heterostructures and/or layer sequences with different doping-types and –concentrations can be fabricated, with interfaces that are abrupt on an atomic level. In recent years, the MBE activities have shifted more and more into the field of self-organization based on lattice-mismatched heteroepitaxy: During pseudomorphic growth, a mismatch between the lattice constants

of two heteromaterials is concomitant with strain in the layers, which leads to the so-called Stranski-Krastanow growth mode. Stranski-Krastanow growth does not support the deposition of one atomic layer after the other, but instead causes three-dimensional island formation and, in this way, partial strain relief. For a high enough lattice mismatch, the resulting islands have nanometer dimension and behave as zero-dimensional quantum dots. Quantum dots confine electrons and/or holes in all three dimensions of space, which leads to a substantial modification of their electronic, optical and magnetic properties. Quantum dots are being used for highly efficient lasers, single photon sources for quantum cryptography and spintronic transport devices, to name just a few applications. At the institute a variety of semiconductor heterostructures are fabricated by MBE. These include group-IV elements (silicon, germanium, carbon, and tin), III-V semiconductor heterostructures (GaAlAs, InSb and others) as well as II-VI (CdTe, CdSe etc.) and IV-VI (PbTe, PbSe, EuTe etc.) heterostructures.

A production-compatible growth technique is metal-organic vapor phase epitaxy (MOVPE), which is used at the institute of the fabrication of group-III-nitrides (GaN, InN and compounds). Group-III-nitrides have become a rapidly growing class of materials in the last decade, mainly because they provide the material basis for light emitting diodes and lasers in the blue and visible spectral range. Because of their comparatively large band gaps, group-III-nitrides become also important for electronic devices that operate under high ambient temperatures, and for high power applications. Moreover, when doped with Mn or Fe, group-III-nitrides become (ferro)magnetic semiconductors with a wide variety of potential applications. A distinctive aim here is the combination of (ferro) magnetic and superconducting properties induced by spin-orbit coupling in a single material system.

Another class of wide-gap semiconductors is based on ZnO and is fabricated by sputter deposition under ultra-high vacuum conditions. This material class is again an important candidate for the combination of semiconducting and magnetic properties, but also for light emitting diodes in the visible and blue spectral range.

Finally, the chemical synthesis of nanocrystals is pursued at the institute, aiming toward optical or magnetic applications. Chemical synthesis allows the fabrication of comparably large amounts of nanocrystals in a single run, which can then be stored in a colloidal solution. Major efforts have been dedicated to the development of entirely new synthesis techniques, and the introduction of inorganic ligands that are essential for current transport in sensor applications. Also, the three dimensional, hierarchical ordering of nanocrystals into super-crystal arrangements has been demonstrated. Several devices were fabricated in collaboration with the industry, e.g. an organic infrared sensor based on semiconductor nanocrystals.

(ii) Nanotechnology

For the implementation of demonstrator devices, but also for electronic and optical characterizations, it is necessary to process the heteromaterials and compounds into functional nanostructures. This task is mainly performed in the cleanroom of the institute, which provides facilities for nano-lithography, anisotropic etching, deposition of metals and insulators, wafer- and wire-bonding and also on-site analytical techniques such as profilometers and on-wafer probers for the assessments of the individual processing steps.

Several lithographic tools are available to fabricate the masks for the subsequent selective processing of the semiconductor heterostructures. Besides optical lithography, which is mainly employed for markers and contact pats, electron-beam lithography (EBL) is used as a general purpose tool for nanostructuring. It is based on a commercial high-resolution scanning electron microscope combined with a beam blanker and a pattern generator. In this way, feature sizes below 20 nm are routinely achieved in polymethylmethacrylat (PMMA) electron-beam resists. EBL is used for transport devices, such as lateral quantum dots, which are defined by a combination of closely spaced electrodes in a two-dimensional electron gas. Another example is the direct contacting of self-organized quantum dots or quantum wires plus the implementation of a gate electrode on top or below them. EBL is also used for the processing of so-called photonic crystals that consist of a periodic array of air-holes in a semiconductor heterostructure. Photonic crystals and resonators have become important building blocks for integrated light processing on a chip level, but also for single photon sources and other advanced optoelectronic applications. Recently, we succeeded in combining top-down and bottom-up processes to implement photonic crystals with perfectly ordered, commensurable quantum dots fabricated by a seeded self-organization process in one of our MBE machines. For this purpose, three levels of e-beam lithography have to be aligned with respect to each other with a precision of < 30 nm. Currently, the electron-beam capabilities at the JKU are being upgraded to allow both ultrafine structural resolution down to a few nanometers and at the same time large areas to be exposed without the necessity of detrimental stitching procedures.

While e-beam lithography is an extremely versatile tool for nanostructuring on a laboratory scale, it is not well suited for larger areas or for high throughput, because the features are written in a sequential way. These disadvantages can be overcome by nanoimprint lithography (NIL). It uses pre-fabricated, transparent stamps to transfer the desired nanostructures into a resist that is hardened by illumination with ultra-violet light. With this technique, feature sizes down to 10 nm have been reported in the literature. We use NIL mainly for large-area photonic crystals, but structuring transistor arrays with this lithography technique has also been demonstrated. We contribute to the development of the NIL technique itself through several industry cooperations in the framework of the Austrian Nano-Initiative and EU projects.

Lithography defines the mask for subsequent nanopatterning, which consists either in an etching or a deposition step. For the former, anisotropic dry etching processes are required to preserve the feature sizes of the un-masked areas. Two reactive ion etching (RIE) reactors are operated in the cleanroom, one of which exploits an inductively-coupled plasma (ICP) and the possibility for cooling the substrates to cryogenic temperatures (cryo-ICP RIE). In this reactor it is also possible to run gas-chopping processes, which are employed for micromechanic devices and via-hole etching through the substrate. For material deposition, conventional evaporation systems, sputter and plasma deposition facilities and an atomic-layer deposition (ALD) system are available. For some applications, the resulting films have to be of extremely high quality, pin-hole free down to only a few atomic layers and with homogeneous thicknesses over large areas. Such films are, for instance, required in field effect transistors in which the channel carrier concentration has to be controlled with single electron precision.

(iii) Nanoanalytics
To characterize the nanostructures, a wide complement of analytical tools is available either at the institute, or via collaborations with external laboratories and synchrotrons.

Structural characterization is based on x-ray techniques, transmission electron microscopy (TEM) and on scanning tunneling microscopy (STM). The institute operates three x-ray diffractometers, and collaborates with several synchrotron light sources (ESRF in Grenoble, BESSY in Berlin, DESY in Hamburg, Elettra in Trieste and others) that can provide much higher x-ray intensities. x-ray diffraction (XRD) is one of the most versatile tools regarding the characterization of strain and composition in heterostructures and self-assembled nanostructures. Conventional XRD set-ups average over relatively large sample areas (mm^2), i.e. until recently the strain characterization of individual quantum dots was not possible in this way. Meanwhile, members of the institute have contributed to the installation of a new beam line at the ESRF, which allows for beam focusing to regions < 100 nm. The capability of this beam line was recently demonstrated with locally resolved strain characterizations of a functional MOSFET device on top of a Ge island. The latter works as a stressor to improve the electron mobility in the device. Similar measurements were performed on nanostructured Ge films that aim at a strain-induced conversion into a direct gap material. Such materials could one day provide integrated light sources for optical interconnects on silicon-based devices.

Transmission electron microscopy is a similarly versatile technique for the characterization of material properties on the atomic level. It is particularly relevant for the assessment of heterointerfaces, quantum dots and nanocrystals. TEM allows for imaging with atomic resolution, but it can also provide the distribution of the elements in a compound or across an interface. A large variety of TEM characterization techniques has been developed in the last years, which allow, for example, the precise characterization of dislocations in solids. With a heatable sample holder, the movement and reaction kinetics of dislocations can then bestudied in vivo. Similarly, the spinodal decomposition of immiscible heterostructures can be investigated in this way, as we could recently demonstrate in the aforementioned PbTe/CdTe material system .

Scanning tunneling microscopy (STM) provides atomic resolution on surfaces rather than interfaces. In combination with an MBE facility, the self-organized growth of nanostructures can be directly monitored in a series of stop-motion images [1]. One of the STMs at the institute has been custom-modified to detect radio frequency oscillations of molecules deposited on a crystalline surface. This allowed recently the detection of the smallest man-made mechanical resonator based on one-dimensional chains of four to seven weakly coupled molecules [2].

For the characterization of electronic and quantum electronic devices several magneto-transport set-ups are available that provide magnetic fields up to 16 T and temperatures down into the milli-Kelvin range. Such low temperatures and/or high magnetic fields are required to study quantum effects of a few interacting electron or hole spins in zero-, one- and two-dimensional configurations. Typical examples are single-electron transistors, which are widely studied as scalable quantum bits (qubits) for future quantum computing devices. In this respect, silicon-based qubits are particularly promising, because of the unrivalled spin coherence times in this material. Moreover, in the framework of a recent ERC Starting Grant and an FWF START-Grant (both to G. Katsaros, Semiconductor Division)), self-organized germanium quantum wires on silicon substrates are combined with superconducting materials. The aim here is to realize topologically protected Majorana Fermions as units for information storage.

For the optical characterization of individual nanostructures several dedicated installations for cw and time-resolved photoluminescence spectroscopy are available at the institute. These cover a wide range of wavelengths to comply with the broad material base with band gaps ranging from the mid infrared to the blue spectral range. Standard setups for optical characterization comprise exciting cw or pulsed lasers of various excitation energies and powers, sample stages that are in many cases cooled down to the temperature of liquid helium, spectrometers for energy resolved scans and (cooled) detectors operating in the spectral range required for the respective experiment. More refined setups use a confocal arrangement of excitation and light detection and allow for spatial resolved measurements to address small ensembles or individual quantum dots and entangled photon sources are characterized using photon-correlation setups based on single photon detectors.

Magnetic materials are characterized by superconducting quantum interference device (SQUID), a cantilever-beam magnetometer and by electron spin resonance (ESR). Instruments for all three types of measurements are available at the institute. In addition, synchrotrons are intensively used in the framework of external collaborations to assess the magnetic and spin properties of materials synthesized at the institute .

(iv) Simulations
Several of the analytical tools require intensive simulations for the interpretation of the experimental data. This certainly applies to

most of the x-ray investigations on strained heterostructures, in particular, when it comes to spatially resolved strain- and composition-experiments on nanoscale objects and individual quantum dots [3,4]. The Finite element method (FEM) is one of the most versatile simulations techniques for this kind of problems. It is based on continuum mechanics, which has turned out to remain essentially applicable down to the nanoscale. Simulation tools are also developed at the institute of x-ray tomography and, more recently, for phase retrieval to allow real-space imaging with x-ray experiments.

Transmission electron microscopy provides real- and k-space imaging simultaneously, but atomically resolved phase contrast images of interfaces always requires extensive simulations to identify the atomic positions. Simulations are also required for the interpretation of specialized TEM techniques, such as the determination of the Burgers vectors of dislocations. FEM simulation are also being used to develop novel piezoelectric-based actuators capable of inducing arbitrary strain configurations to materials and nanostructures.

For a deeper understanding of self-organization phenomena, simulations of the underlying energetic and kinetic mechanisms are required. Numerical solutions of the diffusion equation in the presence of phase transitions [5] and kinetic Monte Carlo simulations are routes followed at the institute and in external collaborations. Another class of problems regards the modelling of photonic structures. A variety of simulation tools are utilized for such problems, which are based on two- or three-dimensional solutions of the Maxwell equations. Examples include finite difference time domain (FDTD) and rigorously coupled wave analysis (RCWA) techniques. Finally, the electron and hole wave functions in quantum dots and quantum wells are calculated in a self-consistent way to assess the energy spectrum and the optical transition probabilites in such low-dimensional structures.

(v) Devices

In most cases, nanostructuring of the fabricated heteromaterials leads to devices that are either characterized in detail to gain further understanding of novel physical mechanisms, or they are used to demonstrate the application potential of a novel combination of material base and nanostructure. Examples include quantum transport devices based on low-dimensional or localized charges and/or spins as building blocks for quantum computation and quantum cryptography, hybrid devices that enable precise control of the electronic structure of semiconductor nanocrystals by integration with piezoelectric actuators for strain tuning [6], and optoelectronic devices based on photonic structures with embedded quantum dots or nanocrystals. Also, combinations of semiconducting and magnetic or superconducting properties are investigated on a device level. Last, but not least, nanostructured heteromaterials are processes into thermoelectric devices with enhanced efficiency. Many of these activities are pursued in collaborations with the industry, often in multinational EU projects.

Impact

In the last 50 years, (digital) electronic devices have induced a transition of the industrialized societies into the age of information technology. Silicon will remain for the time being the dominating material in the fields of conventional computing, mobile phones, photovoltaics and others, but even in these traditional fields, novel, silicon-compatible heteromaterials and concepts are continuously being phased into the production cycles. Silicon-germanium compounds, for example, are being used in microprocessor units since more than a decade, and silicon-dioxide gate insulators have meanwhile been replaced by hafnium-containing oxides because of their higher dielectric constants. Other fields of information technology have used entirely different material bases, in particular when efficient light sources are involved. The indirect-band-gap material silicon is not suited for light emitting devices, and therefore neither for fiber communication nor for the envisaged optical interconnects in mainframe computers and servers. Moreover, there are many more applications in the field of micro- and optoelectronics that have become important over the last years: Examples include every-day lighting with GaN-based light emitting diodes, lasers emitting in the near and mid-infrared spectral range for chemical analyses in gases and pollution tracing in the atmosphere, radar systems and magnetic sensors in cars and many more. Such applications are in most cases based on semiconductor heterostructures with band gaps that are optimized for the specific application.

It is quite easy to predict that these developments will not only continue in the next years, but will do so on an accelerated pace. The ever increasing capability for data transfer and –processing will require new types of sensors to provide a multitude of data in real time. A good example for this trend can be seen in the evolution of electronic components in cars, which already today provide a large number of assistance systems that rely on data gathering and processing with a significant number of interconnected sensor systems. Similar trends are observable in industrial production, where the ever increasing number of robots requires new types of sensors to provide additional functionalities. But also on the level of individual households, home, appliances develop an increasing number of smart functions, again based on sensors, interconnects and information processing.

Based on this background, the activities at the Institute of Semiconductor and Solid State Physics cover in a comprehensive way the ever increasing need for materials and material combinations with novel properties, as well as their processing into devices with nanoscale precision. Many of our activities belong to the category of basic research, thus being far ahead of actual production cycles. Examples include our contributions to the concepts and components for quantum computing and quantum cryptography [6], or the development of multiferroic materials and (semi)-magnetic semiconductors [7]. Activities in these fields aim toward a basic understanding of the underlying (quantum mechanical) mechanisms, and the demonstration of properties that are superior to known solutions in the field of information technology.

Other activities are much closer to production, and have in some cases already led to demonstrator devices. Examples include lead-salt lasers in the mid-infrared spectral range, cost effective organic photodetectors based on chemically synthesized nanocrystals [8] and hetero-nanostructures for thermoelectric applications with enhanced efficiency.

In the long term, our research activities are expected to contribute novel materials and solutions based on nanotechnologies for the increasing demands of the information societies of the 21st century.

References

[1] G. Chen et al., Formation of Ge nanoripples on vicinal Si(1110), Phys. Rev. Lett. 108, 055503 (2012)

[2] S. Mülleger et al., Radio-wave oscillations of molecular-chain resonators, Phys. Rev. Lett. 112, 117201 (2014)

[3] J. Stangl et al., Structural properties of self-organized semiconductor nanostructures, Rev. Mod. Phys. 76, 725 (2004)

[4] N. Hrauda et al.,x-ray nanodiffraction on a single SiGe quantum dot inside a functioning field-effect transistor, Nano Letters 7, 2875 (2011)

[5] H. Groiss et al., Real-time observation of nanoscale topological transitions in epitaxial PbTe/CdTe heterostructures, APL Mat. 2, 012105 (2014)

[7] T. Devillers et al., Manipulating Mn-Mg-k cation complexes to control the charge and spin state of Mn in GaN, Scientific Rep. 2, 722 (2012)

[8] T. Rauch et al., Near-infrared imaging with quantum-dot-sensitized organic photodiodes, Nature Photonics 3, 332 (2009)

Competencies

Our work on Nanostructured Quantum-Electronic, Optic, Magnetic and Spintronic Materials is interlinked with national and international research projects and consortia, and uses synchrotron light sources and dedicated transmission electron microscopy installations throughout Europe. The following list shows a selection of third-party funded projects active in 2014 at the institute, the respective prime investigators and funding agencies.

European Union:
- Towards spin qubits and Majorana fermions in Germanium self-assembled hut-wires (Spajorana) (ERC Starting Grant 335497, G. Katsaros)
- Electronic transport and spin dynamics through SiGe self-assembled quantum dots (Spiderman) (G. Katsaros)
- Silicon Platform for Quantum Spintronics (SiSPIN) (A. Rastelli)
- Nanoparticle Embedded in Alloy Thermoelectrics (NEAT) (A. Rastelli)
- Hybrid Artificial and Natural Atomic Systems (HANAS) (A. Rastelli)

Austrian Research Promotion Agency (FFG)
- Competence Headquarter: Excellence in Electronics Sputtering Target Technology (R. Koch, A. Bonanni)

Austrian Nano Initiative (FFG)
- Platon: Projects: III-V Nanostructures and Silicon Nanostructures for Photonics (T. Fromherz)
- NILAustria: Project: NILquantumdot (T. Fromherz)
- International SFB 025: Infrared Optical Nanostructures (FWF)
- SiGe Nanostructures (F. Schäffler)
- Epitaxial Lead Salt Nanostructures (G. Springholz)
- Nanocrystals for mid-infrared photonics (W.Heiss)
- Next Generation X-ray Techniques (J. Stangl)
- IR Emission and Detection by Group IV Nanostructures (T. Fromherz)

Austrian Science Fund (FWF)
- Towards hole spin qubits and Majorana fermions in Germanium (START Grant, G. Katsaros)
- Quantum transport in self-assembled Ge nanowires (G. Katsaros)
- Helical states in strained ultrathin Ge nanowires (G. Katsaros)
- Investigation of nanowires by x-ray diffraction methods (J. Stangl)
- Nitrides for quantum tunnelling and topological phenomena (A.Bonanni)
- Magnetic nitrides probed via microwave resonance (A. Bonanni)

Proponents

Univ. Prof. Dr. Armando Rastelli
Institute of Semiconductor and Solid State Physics

armando.rastelli@jku.at
http://www.jku.at/hfp

Univ. Prof. Dr. Reinhold Koch
Institute of Semiconductor and Solid State Physics

reinhold.koch@jku.at
http://www.jku.at/hfp

Keywords

Semiconductor Heterostructures, Self-Assembled Semiconductor Nanostructures, Magnetic Nanostructures, Thermoelectric Materials, Molecular Beam Epitaxy (MBE), Metal-Organic Vapor Phase Epitaxy (MOVPE), Electron-Beam Lithography, Nanoimprint Lithography (NIL), Reactive Ion Etching (RIE), Atomic-Layer Deposition (ALD), X-ray Diffraction Techniques, Transmission Electron Microscopy (TEM), Quantum Transport, Quantum Dots, Entangled Photons, Spintronics

Focus Line 2: Smart(er) Products and Production Processes

FL2-01 **Offshoring of Innovation in Small and Medium Sized Businesses**
Coordinators: Matthias Fink, Michael Gusenbauer IFI - Institute of Innovation Management

FL2-02 **Process Automation**
Coordinators: Kurt Schlacher, Institute of Automatic Control and Control Systems Technology, Hans Irschik, Institute of Technical Mechanics

FL2-03 **Product Development**
Coordinators: Klaus Zeman, Institute of Mechatronic Design and Production, Rudolf Scheidl, Institute of Machine Design and Hydraulic Drives

FL2-04 **Smart(er) Polymer Processing Technologies for Resource-efficient Production and Products**
Coordinators: Jürgen Miethlinger, Institute of Polymer Extrusion and Compounding, Bernhard Zagar, Institute of Measurement Technology

FL2-05 **Polymer Injection Moulding and Process Automation**
Coordinator: Georg Steinbichler, Institute of Polymer Injection Moulding and Process Automation

FL2-06 **Drives' & Actuators' role for I 4.0**
Coordinators: Wolfgang Amrhein, Institute of Electric Drives and Power Electronics,
Rudolf Scheidl, Institute of Machine Design and Hydraulic Drives

FL2-07 **Evidence Based Innovation Policies for Additive Manufacturing**
Coordinators: Matthias Fink, Johannes Gartner, IFI - Institute of Innovation Management,

FL2-08 **Optimal Design of Industrial Experiments**
Coordinator: Werner G. Müller, Department of Applied Statistics

Offshoring of Innovation in Small and Medium Sized Businesses

"Innovation offshoring (IO) has become common practice for companies in industrialized countries to re-evaluate innovation processes."

Matthias Fink

Focus Line 2:

Smart(er) Products and Production Processes

Coordinator:

Univ.-Prof. MMag.Dr. Matthias Fink
IFI - Institute of Innovation Management

matthias.fink@jku.at
http://ifi.jku.at/

Research Focus

- Innovation Offshoring
- Small and Medium Sized Businesses
- Evidence Based Research
- International Survey

Vision

Fuelled by advances in ICT, which have reduced communication costs around the globe, non-location-specific tasks such as innovation creation are increasingly being sourced from overseas. Many western multinational enterprises (MNEs) from a broad spectrum of industries, such as Microsoft, General Electric, Intel, Eli Lilly, or American Express, now perform innovative activities in offshore destinations, mainly located in Asia. So-called innovation offshoring (IO) has become common practice for companies in industrialized countries to re-evaluate innovation processes.

Recently, researchers have been identifying and tracking emerging trends that are changing the nature of IO entirely. These trends show that IO is currently picking up pace and undergoing strong transformations. Triggered by new technological possibilities, new managerial practices and new macroeconomic realities we observe a dramatic increase and enhanced routinization of IO, the shift in geographic focus and, most importantly, the emergence of small and medium-sized enterprises (SMEs) engaging in IO.

Among these trends, the offshoring of innovation by SMEs is especially relevant. Business and management research greatly neglects the particularities of SMEs by either (1) considering MNEs as the unit of analysis or (2) not including the size criterion at all. Only a few studies in IO research consider the size criterion and even fewer explicitly target SMEs. This is surprising, as the importance of firm size in business research is acknowledged. It is widely accepted that 'A Small Business is not a little Big Business', indicating that SMEs have different qualities, needs and capabilities, which cannot be associated directly to their size but are linked to their specific attributes. It is not enough to investigate SMEs as part of a sample involving all size groups, as SMEs have to be examined in their own context. An approach including variables accounting for both SMEs and MNEs would compromise the explanatory power of the results.

Furthermore, SMEs are often seen through the eyes of MNEs, with the variables tailored to the latter. Such approaches can be problematic, skewing the results and leaving certain aspects undetected. Small business research especially highlights the two disadvantages which SMEs typically face in innovation processes: first, the liability of smallness denotes the lack of a critical mass of resources needed for innovation projects, and second, the liability of outsidership refers to the lack of SMEs in new management approaches such as IO. Looking at the limited capabilities of SMEs, the necessity of SME-specific parameters becomes evident. Unlike their bigger counterparts, SMEs are assumed to be unable to take advantage of captive operations, which limits their spectrum of governance modes. Considering their increased fragility, issues such as intellectual property (IP) protection and the outsourcing of core competencies have a greater impact. These are just some of the particularities that illustrate the need for SME-centered research into IO. Kenney et al. [1: p. 893] state that "still further research is necessary to understand the extent of offshoring innovation by small- and medium-sized enterprises (SMEs), and the amount of research, relative to development, that these firms offshore."
Despite a substantial increase of efforts since 2008, research has not caught up with the rapid developments in IO in two ways: First, it is widely noted that there is still a great lack of empirical firm-level data on different aspects of IO. The great dynamics of international business add to the urgency of conducting research. Because of IO's steadily increasing scale and scope new trends remain under-researched. Second, there is still no conclusive academic study on the status quo of IO-research and in SME IO practices. Currently, there are rapid developments in business practice on the one hand, and academia which has no clear understanding of the gaps which still have to be filled on the other. The field of IO by SMEs remains largely fragmented and unmapped.

To sum up, research on IO by SMEs is almost non-existent. This void demands new empirical data focusing explicitly on SMEs and taking into account their particularities in sourcing innovation internationally. This study is conducted within a stream of research that has only been noticed recently and whose importance is predicted to increase further in the future.

Approach

The study is designed to cover a spectrum of methods typically used in empirical social science, both in data collection and analysis. Each of the steps will add value through its distinct research design and will build on the chronologically preceding step: building on the systematic literature review in the tradition of evidence based research we will generate and test SME specific hypotheses regarding IO. All steps comprise qualitative as well as quantitative elements. Such a sequential mixed-method approach that addresses diverse, constitutive goals without endangering scientific rigor is especially recommended for IO research as this is a phenomenon that is tightly embedded in the social fabric.

Impact

This study will provide the first extensive and insightful picture of IO in SMEs. The findings will be highly relevant for both science and practice. We aim to participate in the international academic debate by tackling blind spots in the young field of research into IO by SMEs in three ways. First, it will offer the first comprehensive review of IO literature, mapping out the thematic foci and illustrating the research gaps. By identifying these gaps, it will provide an agenda for future research and help to direct attention towards currently unstudied areas in the IO field. Second, it will provide systematically developed, original hypotheses that are specific to SMEs. These genuine hypotheses will provide an improved capability to explore the nature of SMEs' IO, and will therefore improve the quality of the research significantly. Considering the growing importance of this field of research, these hypotheses will provide great value for future studies on SMEs' IO. Third, this study will make a valuable contribution to empirical research, extending the empirical foundations of IO research on SMEs. It will be one of the few studies in this field of research to have quantitatively tested a wide range of relevant hypotheses. The mixed-method design of the proposed study should ensure that the whole is more than the sum of its parts, increasing its credibility and validity. This research is not only relevant to innovation studies and international business research, but will also contribute to the field of international entrepreneurship and small business management. Investigating this relatively young topic could help to lead the field in new and unexplored theoretical directions.

The theoretical and empirical insights to be gained from this proposed study have practical implications on three levels. First, for business management in general, and especially for the management of SMEs, it is important to get answers to the very core questions of IO practices at the micro level. The relocation of the sensitive function of innovation requires deep understanding of the internal and external factors encompassing the innovation process. The management of SMEs will profit from the results of this study because they will provide orientation as to how to cope with the liabilities of smallness and outsidership. This empirically grounded research will give SMEs a useful benchmark for their IO activities. Furthermore, the findings on SMEs' international innovation-sourcing strategies and best practices will provide valuable insights for companies considering similar strategies. Second, this study is important for MNEs as well. Since SMEs, and especially ventures, are valuable sources of large firms' innovativeness (i.e. through collaboration or acquisition), their IO decisions have an impact, not only on their own sphere, but also on that of MNEs. Given the importance of SMEs' innovation strategies, it would be dangerous to leave this aspect of IO research neglected [2]. Third, this empirical study will inform policy makers, thus improving the quality of decisions on innovation policy. Only if the underlying mechanisms are well understood will it be possible to formulate effective policies for innovation and growth. With the findings of this research, it will be easier to establish conditions favourable to IO by SMEs. SMEs are more innovative than large firms, making them a prime target for innovation policies – a fundamental part of economic growth policies at every level [3]. A blind spot regarding SMEs' IO could leave important microeconomic processes undetected, affecting a large proportion of a country's firms.

References

[1] M. Kenney, S. Massini and T. Murtha: "Offshoring administrative and technical work: New fields for understanding the global enterprise", Journal of International Business Studies, Vol. 40, No. 6, pp. 887–900, 2009.

[2] B.M. Sadowski: "Towards Market Repositioning in Central and Eastern Europe: International Cooperative Ventures in Hungary, Poland and the Czech Republic", Research Policy, Vol. 30, No. 5, pp. 711–724, 2001.

[3] Z. Ács and D.B. Audretsch: "Innovation and small firms", Cambridge (Mass.); London: MIT Press, 1990.

[4] T. Kautonen, M. van Gelderen and M. Fink: "Robustness of the theory of planned behaviour in predicting entrepreneurial intentions and actions", Entrepreneurship Theory & Practice, DOI: 10.1111/etap.12056, 2013.

[5] A. Moro and M. Fink: "Loan managers' trust and credit access for SMEs", Journal of Banking and Finance, Vol. 37, No. 3, pp. 927-936, 2013.

[6] WKOOe, Academia Superior, PIC (Eds.): W3 - Wirtschaft.Wissen.Wachstum: Eine wirtschaftspolitische Reformagenda für OÖ, Wachstumsorientierte und innovative Unternehmensgründungen in OÖ (P. Polgar/N, Kailer/Lefenda, J./G. Pöchhacker-Tröscher), Linz, 2012.

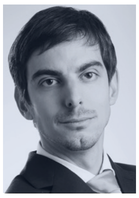
[7] R. M. Bauer and W.M. Eagen: "Design Thinking as Multi-Epistemic Intelligence in Organisations", in I.W. King and J. Vickery (eds.), Experiencing Organisations: New Aesthetic Perspectives, Faringdon, UK: Libri; pp. 137-155, 2013, and "Designing — Innovation at the Crossroads of Structure and Process", in M. Shamiyeh (ed.), Creating Desired Futures. Basel - Boston - Berlin: Birkhäuser, pp. 145-163, 2010.

Competencies

This research builds on a stream of research and publications [e.g. 4, 5] in the area of international entrepreneurship and small business management that was funded by the Austrian Academy of Sciences (APART), the Austrian National Bank (OeNB) and Erste Bank. However, only when Michael Gusenbauer joined the Team of the Institute of Innovation Management (IFI) and contributed his expertise in the field of innovation offshoring, which he had gained from participating in the NEURUS program at the University of Illinois at Urbana-Champaign, the idea for this project was born. With an excellent concept, it was easy to win Iris Fischlmayr (Department of International Management), Norbert Kailer (IUG - Institute of Entrepreneurship and Organizational Development) and Robert Bauer (Institute of Organization and Global Management Studies) with their complementary expertise as partners in this project.

Funded by TEKES (Finnish Technology and Innovation Fund), broad research on virtual working in teams and its various consequences on different levels, has been conducted by researchers of Department of International Management at JKU and their Finnish colleagues, ending up in a training concept based on an online business simulation supporting teams to collaborate globally via ICT. Among other factors, virtual shift work resp. applying the “follow the sun principle” in order to use working times around the globe to their full extent, especially for R&D and innovation, is included in both the training and the underlying as well as resulting research. These aspects go hand in hand with the idea of offshoring resp. IO and are applicable to MNEs as well as SMEs. A growing number of globally operating companies in Finland and Austria already participate in this training to ameliorate the skills and understanding of their virtually working employees, especially with regard to knowledge transfer in the scope of virtual shift work. The IUG contributes to the understanding of IO in SME by contributing its expertise in entrepreneurial intention of (potential) entrepreneurs and in the support of start-ups as well as in the development and cooperation of young enterprises including competency development of entrepreneurial teams and small businesses. In this research stream the team of the IUG - Institute of Entrepreneurship and Organizational Development strongly accounts for the regional institutional context in which SMEs operate [6].
Funded by the Austrian Research Promotion Agency and by an industry partner the Institute of Organization and Global Management Studies is currently conducting a qualitative long-term study of globally distributed innovation processes, with a particular emphasis on Austria and China. This research includes cases of both off-shoring and back-shoring of R&D. In addition, the Institute contributes its expertise in conceptualizing processes of industrial creativity [7], which enables fine-grained, precise examination of IO (i.e., which parts of the creative process are expected to be off-shored under what conditions).

Proponents



Univ.-Prof. MMag.Dr. Matthias Fink
IFI - Institute of Innovation Management

matthias.fink@jku.at
http://ifi.jku.at/

Dr. Michael Gusenbauer
IFI - Institute of Innovation Management

michael.gusenbauer_1@jku.at
http://ifi.jku.at/

A.Univ.-Prof.in Mag.a Dr.in Iris Fischlmayr
Department of International Management

Iris.fischlmayr@jku.at
http://www.jku.at/iim

Univ.-Prof. Mag. Dr. Norbert Kailer
Institute of Entrepreneurship and
Organizational Development

norbert.kailer@jku.at
http://www.jku.at/iug

A.Univ.-Prof. Mag. Dr. Robert Bauer
Institute of Organization and
Global Management Studies

robert.bauer@jku.at
https://www.jku.at/org

Keywords

Innovation Management, Entrepreneurship, International Management, Organization Studies

Process Automation

"In process automation engineering and natural sciences meet computer and information sciences to combine the physical world of processes with the logic, mathematical world of guidance and control."

Kurt Schlacher

Focus Line 2:

Smart(er) Products and Production Processes

Coordinator:

O.Univ.-Prof. DI Dr. Kurt Schlacher
Institute of Automatic Control and
Control Systems Technology

kurt.schlacher@jku.at
http://regpro.mechatronik.uni-linz.ac.at/

Research Focus

- Dynamics and Model Based Control
- Distributed Actuator and Sensor Systems
- Computer Based Method (numeric and symbolic ones) for Dynamical Systems

Vision

Any new generation production process must preserve resources like energy, raw materials or environment; additionally recycling and reuse must be supported. Entities, which are/were acting independently, must interact, where interaction means exchange of any type of resources, but also of information. Here information must not be confused with data, whose exchange is technical standard. **Autonomous entities** of production processes are machines, structures or even production lines **equipped with sensors and actuators connected by networks** and **controlled by distributed intelligent devices** based on many processor systems. Here engineering and natural sciences meet computer and information sciences to combine the physical world of processes with the logic, mathematical one of guidance and control. The complexity of these plants will increase extensively, therefore, **new methods**, which are able to master these challenging problems, must be introduced into design and operation of future production systems.

Dynamics and **model based control** are both rapidly expanding scientific fields and **fundamental disciplines of mechatronics.** They share demanding mathematical and/or system theoretic formulations and methods. One vision is to apply these formulations and methods to the analysis and simulation of complex physical phenomena in controlled and dynamically loaded structures and machines for production processes. The complexity of today‘s production systems results from the interaction of technologies from different engineering fields in parallel with application of technologies of different generations. Next generation technologies are required to overcome these problems, where **autonomous controlled machines, structures and processes are the keys for the improvement of production systems.** Model based control combines the physical world of engineering/natural sciences with the abstract world of computer science and mathematics. The progress of communication and information technologies enables this approach in almost any industrial relevant application. In addition the contemporary variety of actuators and sensors allows us to collect an enormous amount of data about the process and to interfere almost wherever it is required. But a sound **theoretical basis**, which is open for any type of innovation, is the prerequisite to master the complexity of production processes. A unifying analysis followed by multi physics simulations, which includes data processing and control, is followed by model-based design for hard- and software. Rapid prototyping supports the design of new and improvement of existing processes, as well as advanced modeling methods, e.g. the geometric framework of extended Hamiltonian and Lagrangian systems and beyond, the theory of hybrid systems together with the combination of symbolic and numerical methods. The main vision is the application of theoretically developed methods, which have proven to be successful at a laboratory and/or university, academic level to the design of next generation production systems or to a significant improvement of existing plants.

Approach

Advanced scientific methods, combined with the experience in development and **operation of plants**, are necessary to let the vision become reality. Some major topics, without claiming completeness, are:

Development of mathematical **models for hard- and software** to unify the design of processes together with actuators, sensors and controllers, also applicable to fault detection/isolation as well as monitoring.

Improvement of **computer based methods for dynamic systems** and production processes, e.g. finite element methods, multi-body dynamics, multi physics simulations, controller design with symbolic and numerical approaches etc.

Improvement of software with respect to **self-configuration** for real time applications in control and guidance systems.

Increase of **safety** of production processes, of the connecting networks including data exchange, by monitoring as well as with embedded systems based on sensors and networks integrated in the structure.

Fast prototyping based on proprietary hard- and software but even more important based on open software and hardware with unfolded functionality to increase the applicability and reliability.

Fundamental research for the **development of smart structures** based on novel materials with embedded actuator/sensor networks for applications like adaptive structures, structural health monitoring, energy harvesting and virtual component design.

Novel design of **secure sensor/actuator networks** for real time monitoring, control and guidance.

Optimizing of the **flow of energy** and **raw materials** in plants by advanced control strategies like model predictive control etc.

Impact

Scientific impacts
Smart production together with automation of next generation plants requires research in all involved fields, as well as interdisciplinary research, both at the highest level. From a system theoretic point of view one has to deal with complex hybrid systems, which must meet the requirements of today‘s and tomorrow‘s challenges. Therefore, new methods for complex systems must be developed, which support unifying modeling of multi physical systems on different time scales, applicable to problems of system analysis and system design including hard- and software. The complexity must be reduced by newly developed methods combined with computer based tools for analysis, design and construction, but also for control, monitoring and plant operation in general. Actua-

tor and sensor systems will be connected by secure networks for real time applications dealing with processes of fast and complicated dynamics. This requires new ways to understand the desired and reachable **functionality of complex hybrid systems** with a strong impact on all involved fields. In particular methods of all these scientific disciplines must be combined to a new approach such that the achievement potential of each method is not reduced after its integration into the new way of thinking. A major challenge for the research is that success is not only measured by methods of academic metrology, but also by experiments at a laboratory or small plant scale. Therefore a serious **cooperation of applied and basic research** is undoubtedly required.

Economic and societal impacts

Smart machines, structures and **automation** are the starting point for smart production and smart products. **Smart production** is more flexible and offers a more careful handling of resources. Therefore, the creation of values can remain in high-wage countries. In a long term the number of lower skilled jobs will decrease, but the number of jobs for experts will increase significantly. One may expect a strong impact on the educational system, in particular on technical universities and faculties. A short term consequence will be the upgrading of certain industrial sectors in Austria to meet the demands of a more modern production. In addition, Upper Austria has the possibility to become one of the leading centers in smart production research.

References

[1] M. Schöberl and K. Schlacher: “On an implicit triangular decomposition of nonlinear control systems that are 1-flat - a constructive approach”, in Automatica, accepted and in press, 2014.

[2] T. Rittenschober and K. Schlacher: “Observer-based self sensing actuation of piezoelastic structures for robust vibration control”, in Automatica, Vol. 48, No. 6, pp. 1123–1131, 2012.

[3] M. Schöberl and K. Schlacher: “On an intrinsic formulation of time-variant Port Hamiltonian systems”, in Automatica, Vol. 48, No. 9, pp. 2194-2200, 2012.

[4] J. Schöftner and H. Irschik: “A comparative study of smart passive piezoelectric structures interacting with electric networks: Timoshenko beam theory versus finite element plane stress calculations”, in Smart Materials and Structures, Vol. 20, 025007-1-025007-13, 2011.

[5] A. Siuka, M. Schöberl and Schlacher K.: “Port-Hamiltonian modelling and energy-based control of the Timoshenko beam - An approach based on structural invariants”, in Acta Mechanica, Vol. 222, No. 1-2, pp. 69-89, 2011.

[6] H. Irschik, M. Krommer, Y. Vetyukov: “On the Use of Piezoelectric Sensors in Structural Mechanics: Some novel strategies”, in Sensors, Vol. 10, No. 6, pp. 5626-5641, 2010.

[7] D. Huber, M. Krommer and H. Irschik: “Dynamic displacement tracking of a one-storey frame structure using patch actuator networks: Analytical plate solution and FE validation”, in Smart Structures and Systems, Vol. 5, pp. 613-632, 2009.

[8] J. Schöftner and H. Irschik: “Passive damping and exact annihilation of vibrations of beams using shaped piezoelectric layers and tuned inductive networks”, in Smart Materials and Structures, Vol. 18, p. 125008, 2009.

[9] H. Irschik, M. Krommer, M. Nader and C. Zehetner: “Mechatronics – The Innovation Request”, in Advances in Science and Technology, Vol. 56, pp. 1-10, 2008.

Edition of Books:

[10] H. Irschik, M. Krommer and A.K. Belyaev (eds.): “Advanced Dynamics and Model-Based Control of Structures and Machines”, Wien: Springer, ISBN 9783709107966, 2012.

[11] H. Irschik, M. Krommer, K. Watanabe and Furukawa T., (eds.): “Mechanics and Model-Based Control of Smart Materials and Structures”, Wien: Springer, ISBN 9783211994832, 2010.

[12] H. Irschik and K. Schlacher (eds.): “Advanced Dynamics and Control of Structures and Machines”, in: CISM Courses and Lectures No. 444, Wien: Springer, 2004.

Competencies

Smart production is a **highly interdisciplinary** field, where success is possible only if research partners of all involved fields are included. The Johannes Kepler University in general, and the faculty of engineering and natural sciences in particular but not exclusively, is able to cover several of these fields.

This has been proven many times by research projects funded by national or international institutions. Without any claim for completeness **Christian Doppler Laboratories** or **Comet Kx competence centers**, in particular the **industrial research center LCM**, where more than forty industrial partners do research with national and international academic partners, should be mentioned.

Proponents

O.Univ.-Prof. DI Dr. Kurt Schlacher
Institute of Automatic Control and Control Systems Technology

kurt.schlacher@jku.at
http://regpro.mechatronik.uni-linz.ac.at/

O.Univ.-Prof. DI Dr. Dr.h.c. Hans Irschik
Institute of Technical Mechanics

hans.irschik@jku.at
http://www.jku.at/tmech

Keywords

Automatic Control, Engineering Mechanics, Health Monitoring, Structural Control, Advanced Automation

Product Development

"We expect significant scientific and technological impact on the integration of modeling and simulation of complex systems for product development and production."

Klaus Zeman

Focus Line 2:

Smart(er) Products and Production Processes

Coordinator:

O.Univ.-Prof. DI Dr. Klaus Zeman
Institute of Mechatronic Design and Production

klaus.zeman@jku.at
http://www.jku.at/imdp

Research Focus

- Engineering design science: Methodologies for interdisciplinary design processes, model-based design of mechatronic systems
- System modelling for mechatronic design: Hierarchical (multi-level) modelling of interdisciplinary systems and products, reduced order modelling, model reduction
- Modelling and simulation of production processes and systems for model based design and control

Vision

Methods and tools for **product development and design** have been changing dramatically during the last decades. The replacement of drafting machines by powerful 3D CAD systems shows only one very obvious evidence of this change. The introduction of information and communication technologies (**ICT**) into all processes of product engineering (especially into product development and production) on a broad front, however, has led to much deeper changes than just the application of CAD or CAM tools. It initiated a tangible, still ongoing **revolution in product development and production**.

More and more **phases of a product's life cycle** - reaching from the first ideas over product planning, development, manufacturing, assembling, commissioning, operation and use, up to recycling together with **essential product aspects** (i.e. important product properties, such as product behavior, usability or ease of production) are captured, described, analyzed, evaluated, controlled and managed virtually, i.e. on the basis of **digital representations** and the application of **computational methods**. This can be done long before the product is available in that **"physically" representation** as it is intended to be finally perceived by customers, either as a material good or service or as a combination of both.

The ever increasing potentials of ICT have been offering totally new and even unexpected possibilities, technologies and methods (CAx-technologies and systems, virtual prototyping approaches, digital mockups, virtual environments etc.) for **virtual (digital) product development and production**. The diffusion of these new technologies and methods into **product development and production** has not only changed the way how product developers are acting and thinking, but has at the same time enabled a huge variety of new results of these processes, namely of **significantly improved and even totally new products.** The development of more and more product variants **individually customized** to specific needs (mass customization, lot size 1) along with still shrinking **time to market** has become an obvious reality that would not have been becoming possible without these new technologies. Thus ICT has already been heavily impacting product development and production both as a process and as the result of this process, the product.

The **physical (mainly spatial) and functional integration** of electronics and software into (often mechanical) products along with the miniaturization of (electronic) components (sensors, actuators, micro-controllers, storage media etc.) has opened the way for improved and advanced products in terms of significantly extended functionality, improved behavior, usability and other important properties. Generally, this has led to "intelligent" or "smart" products exhibiting capabilities of self-learning, reasoning, decision making, adaptability, and finally more and more autonomous features.

The nature of such systems was characterized by Tomizuka already in 2000 [1] by the following definition of **mechatronics**, respectively **mechatronic systems:** "*Mechatronics is the synergistic integration of physical systems with information technology and complex decision-making in the design, manufacture and operation of industrial products and processes.*" This definition not only allows mechanical systems but any "*physical system*", e.g., biological, medical, economical or even computer systems to be the object of such integration. Tomizuka explicitly addresses the **design of industrial products and processes** as an essential issue of mechatronics. The meaning of design in this context can be interpreted twofold, addressing both the **design process** as well as the result of this process, namely the (industrial) **products or processes under design**. Nowadays, a great majority of products as well as the processes for their production can be characterized as mechatronic, highly interdisciplinary, systems.

Due to the interdisciplinary nature of such industrial products and processes, the respective product development and design processes had to be adapted as well, with the goal of a beneficial integration of solution principles from different disciplines (mechanical engineering, electrical engineering/ electronics, ICT) to superior products. The design methodology for mechatronic systems as described in VDI guideline 2206 [2] is exactly devoted to this goal emphasizing particularly on (i) **system design**, (ii) **system integration**, (iii) **assurance of product properties** (virtual and physical performance checks) and (iv) **modeling and model analysis** for computer-aided design and analysis of system properties.

VDI guideline 2206 already includes essential ideas of **cyber physical systems** (**CPS**), regarding mechatronic systems as physical systems that might be "created on a higher level to interconnected systems, which are connected only via information processing", thus opening new potentials to benefit from improvements and optimizations on higher system levels (e.g. distributed systems).

"**Mechatronic design approaches**" (again with twofold meaning) as proposed in [2, 3] are intended to support the dissemination of mechatronics into products and production processes. We like to denote this trend as "**mechatronization of products and (production) processes**", indicating the deployment of mechatronic concepts to products and (production) processes, machines and plants. All this heads to optimize and fully control the process as well as the manufactured product properties, in terms of product quality, throughput and yield, flexibility, reliability and reproducibility of production, safety, resource consumption, environmental impact, and costs.

The mechatronisation of products and processes has increased the **complexity** of products, development and production processes. More and more companies are becoming aware that mastering this complexity is an increasingly crucial factor for their business success and more systematic approaches are needed.
Mechatronic Design in the sense of synergistically integrating and synthesizing solutions from different disciplines to a superior product accompanied by modeling and analysis claims a **paradigm**

change in product development from (isolated) discipline-specific design to a **consistent, model based mechatronic system design approach**. (Mathematical) modeling and analysis should address (i) all relevant system levels (from the overall system under consideration and its embedding into a super-ordinate system or a network, down to specific, single parts of this system) as well as (ii) all phases and associated aspects of the product life cycle by establishing a consistent model base across the different system levels and along all phases of the product's life cycle.

Such a **product model base** is a pre-requisite for a comprehensive and consistent **co-existence of virtual (digital) with physical products**, thus enabling the **vision of seamless, model based design, prediction, guidance, control and tracking of virtual and physical product properties along all phases of a product's life cycle**. The model base will facilitate a beneficial interaction between product development and production. Thus it will significantly contribute to the realisation of Cyber-Physical Systems (CPS), especially of **Cyber-Physical Production Systems (CPPS) and Cyber-Physical Products (CPP)**.

Approach

During the last decades, powerful modeling tools (CAx-systems) have been developed for various specific aspects of product design and production such as 3D-geometry, kinematics, kinetics, mechanical stresses and strains, fatigue, hydraulics, electromagnetism, electrical circuits, automation, control, manufacturing, quality assurance. Initially, these modeling tools were generated predominantly in isolation from one another. In a further step, some of the modeling tools were merged aiming at the integration of some modeling and simulation aspects in product design, e.g., of **geometry** (CAD) **with mechanical stresses** (FEM), of **geometry** (CAD) **with manufacturing** (CAM). "Multi-physics modeling and simulation" is now an established branch in science and engineering. However, a comprehensive, consistent integration of modeling and simulation together with adequate software tools for the manifold multi-disciplinary, multi-level and multi-objective tasks in product design and production is still far away from reality [2, 3, 4, 5, 6, 7]. Although today's hardware and software technologies are offering extensive computer aid, the theoretical, semantic base for a consistent and **comprehensive integration of models across different disciplines**, **system levels** and **along different product life cycle phases** is still rather insufficient. Hence, the proposed approach aims at the significant improvement of the theoretical modeling base as a crucial precondition for a consistent, integrated modeling and simulation framework for the support of product design and production.

A **product model base** as described in the VISION above can be interpreted as a framework for establishing and configuring **consistent, comprehensive and integrated "product models" for product design and production**. To be consistent, comprehensive and integrated, such product models have to cover not only product defining information, but also a plenty of other information and knowledge that is of relevance for all phases and aspects of the **whole product life cycle** (comprising the total multitude of all phases, variants, mutations etc. of a "product class") as well as the **lifetime of a specific, individual product variant** (specific instance of the "product class"). This claim addresses several levels, relations and aspects of a product such as: (i) the product itself as the "**overall system under consideration**" (SuC), (ii) its **sub-systems**, components, elements, and parts, (iii) the **interrelations and interactions** between the system elements and the system's environment, including its incorporation into a super-ordinate system or its embedding into a network of other products, agents, clients etc. which it should communicate, co-operate or interact with, as well as (iv) the essential product properties such as functionality, usability, durability. Furthermore, (v) such product models should be able to consistently integrate and provide information from one phase to other phases of the product life cycle (both feed forward and feedback) **as multi-phase models**, as well as from one system level to others (both bottom up and top down) **as multi-level models**.

The research challenges and open questions described in the VISION have been addressed by several research groups dealing with mechatronics and mechatronic systems. Several efforts have been trying to approach the picture sketched in the VISION, but all of them are still far away from this ideal. The reasons for that are manifold; some of them are (i) the lack of an integrated modeling language that is widely accepted and used by all disciplines of mechatronics, (ii) isolated applications of highly specialized, discipline-specific software tools (CAx-tools), (iii) the lack of platforms for a consistent integration of discipline-specific models and tools, (iv) the lack of a common, discipline-spanning model base, (v) the predominant orientation along available software tools rather than along the essential modeling tasks, and hence, model requirements, (vi) the lack of "reduced", suitably simplified models to integrate them to models of "higher level" systems, i.e. of complex systems comprising diverse and multiple elements as well as intricate interactions between them.

The proposed approach aims at the development of an interdisciplinary modeling framework for the integrated and consistent modeling and simulation of product properties along all phases of the product life cycle and across different hierarchical levels of the product. Elements of this approach are (i) a significant **characterization of the system (product) under consideration** by establishing criteria and rules for the assignment of specific product properties and product data to according product life cycle phases and different system levels leading to a (hierarchical) **model structure of the system** (product) under consideration and its properties; (ii) an appropriate distinction between **micro-level (local) properties** resulting from the system under consideration itself and **macro-level (global) properties** resulting from the interplay of the system of consideration with other systems, i.e., with the (higher order) system or network of systems which the system of consideration is embedded into; (iii) the (automated) extraction of micro-level properties that are of relevance for the interplay with other system elements (and hence for macro-level properties) by reduced order modeling using mathematical methods as well as engineering methods as a bottom up approach for establishing system models from “white box” models of its sub-systems; (iv) the integration of isolated, discipline-specific models to an integrated system model of the next-higher system level; (v) system modeling as a top down approach for system design, i.e., establishing system models from “black box” models of its sub-systems, thus specifying the requirements for these sub-systems.

Research methods for the accomplishment of the above mentioned goals are, e.g., reduced order modeling, feature based design, semantic modeling, knowledge based engineering [3, 4, 5, 6, 7]. The modeling framework with its model structure has to be evaluated and adapted with respect to the requirements for an integrated, consistent modeling approach by means of real world problems from product design and production, thus proving the relevance and applicability of the underlying theoretical concepts.

Impact

We expect significant **scientific and technological impact** on the integration of modeling and simulation of complex systems for product development and production. The intended modeling framework will contribute to a better understanding of complex products and production systems on different levels of abstraction including the evolution of system properties along the creation of such systems. This hierarchical structure of system properties and related models will help to focus on those system properties that are most essential for the different (sub-system) levels and life cycle phases by supporting the analysis, integration, architecting, design, virtual prototyping and testing of such systems. On the other hand, this will help to extend the modeling basis for the further development of future CAx-systems by specifying relevant requirements for the according models.

Furthermore, this modeling framework is a pre-requisite to make (physical) products and their properties accessible to the virtual, digital world of “cyber space” and to actually merge physical products and production systems (e.g. factories) with an adequate, virtual representation of such objects. This will open and extend the realization and applicability of “Cyber Physical Systems”, in particular, of “Cyber Physical Production Systems”. Libraries of significant models together with their parameters are more and more required to become a technological standard for the virtualization of products and production systems.

Economic impact is expected in terms of improved and even totally new products and production performance (e.g., precision, flexibility, throughput, yield). The scientific and technological findings will feed the theoretical modeling framework that is required to realize the intended horizontal and vertical integration of production. This will extend the flexibility and possibilities for individually customized mass products with superior product properties (mass customization, lot size 1). The intended integrated, consistent, comprehensive modeling and simulation framework will allow for the realization of tasks and functions on higher system levels (e.g. optimization with respect to different, varying criteria). The increased flexibility and variety of products and production together with tasks and functions on higher system levels and reduced time to market will lead to improved and new engineering and business processes with significantly improved effectivity and efficiency, to new products and business chances.

Improved product properties together with resource effective, optimized production processes are a must to keep product development and production in high-wage countries such as Austria.

References

[1] M. Tomizuka: “Mechatronics: From the 20th to 21st Century”, 1. IFAC Conference on Mechatronic Systems, Darmstadt, Vol. 1, pp. 1–10, 2000.

[2] VDI Guideline 2206: “Design methodology for mechatronic systems”, VDI Publishing Group, Düsseldorf, 2004.

[3] M. Follmer, P. Hehenberger, S. Punz, R. Rosen, K. Zeman: “Approach for the creation of mechatronic system models”, Proc. Int. Conf. on Engineering Design ICED‘11, Design Society, Copenhagen, Technical University of Denmark, pp. 258-267, 2011.

[4] A. Sadlauer, P. Hehenberger, K. Zeman: “Enhancement of Mechatronic-System-Models”, Proceedings of the ASME 2013 IDETC&CIE Conference, ASME, Portland, 2013.

[5] R. Scheidl, B. Winkler: “Model relations between conceptual and detail design”, Mechatronics, Volume 20, Number 8, pp. 842-849, 2010.

[6] P. Foschum, A. Plöckinger, G. Weidenholzer, R. Scheidl: “TRIZ, Design Optimization and Suh‘s 1st Axiom - a Comparison on the Example of Fast Switching Valves”, 13th Mechatronics Forum International Conference – Mechatronics 2012, Linz, Austria, Series Advances in Mechatronics, Volume 2, R. Scheidl, B. Jakoby (eds.), Trauner Verlag, pp. 498-505, 2012.

[7] T. Pumhössel, P. Hehenberger, K. Zeman: “Model reduction of a parametrically excited drivetrain”, Proc. of ASME 2012 Int. Design Engineering Technical Conferences & Computers and Information in Engineering Conference IDETC/CIE, 2012.

Competencies

The **Institute of Mechatronic Design and Production** and the **Institute of Machine Design and Hydraulic Drives** have a long tradition in basic and industrial research regarding engineering design, design methodology, and **"Mechatronic Design"** [3, 4, 5, 6, 7]. Several projects within the K-plus competence center LCM (Linz Center of Mechatronics) as well as the COMET K2-center ACCM (Austrian Center of Competence in Mechatronics) have been devoted to a broad variety of related topics, comprising design methodology, design tasks for hydraulic and electrical systems as well as for industrial plants, parametric design, model based system design, system modeling, model reduction methods, design and modeling languages, mechatronic design ontologies, design process models etc.. Mathematical modeling on a physical basis, analytical and numerical methods are the most important ingredients for the derivation of a plenty of analytical, semi-analytical and numerical models of production processes and systems as well as "components" like hydraulic or electrical drives. Another class of models comprises procedure models of design processes addressing the structuring, realization and control of design processes. The central link between both worlds, i.e. between mathematical modeling of production processes, systems and components and model based design, is the models.

Both institutes are well embedded in the relevant scientific communities of their research topics including international contacts and memberships in scientific societies for product development, hydraulics etc.. Furthermore, they are strongly involved in basic and industrial research projects conducted in the framework of the **ACCM**. As an example, an actual, central project there addresses system models for mechatronic design. Together with four industrial partners, the project aims at building system models from mainly isolated, discipline-specific product models by integrating them on the next-higher system level. Basic questions regarding the existing models and the system models to be built from these mainly isolated models have been investigated leading to a "model map" including characteristic features of the underlying models such as the original system to be modeled, its interfaces to the environment, modeling purposes and questions, load, resp. test scenarios, flow of input and output data, "model owner" and a lot more.

The research group has a lot of knowledge and experience in **mathematical modeling methods and tools**, in **design methodology** as well as in **designing and realizing setups for experimental testing and model validation.**
Some of our industrial partners are voestalpine, Siemens VAI, Trumpf Maschinen Austria, Bosch Rexroth, Engel, Pöttinger, Siemens Corporate Technology Munich.

Proponents

O.Univ.-Prof. DI Dr. Klaus Zeman
Institute of Mechatronic Design
and Production

klaus.zeman@jku.at
http://www.jku.at/imdp

O.Univ.-Prof. DI Dr. Rudolf Scheidl
Institute of Machine Design
and Hydraulic Drives

rudolf.scheidl@jku.at
http://imh.jku.at

Keywords

Product Development, Product Design, Mechatronic Design, Mechatronisation of Products and Production Processes, System Design, Product Modeling

Smart(er) Polymer Processing Technologies for Resource Efficient Production and Products

"According to our maxim 'Resource Efficient and Cleaner Production and Products' we combine the increase of production and resource efficiency, with the development of products that both meet the principles of eco-design and realise their full process and material potential."

Jürgen Miethlinger

Focus Line 2:

Smart(er) Products and Production Processes

Coordinator:

Univ.-Prof. DI Dr. Jürgen Miethlinger MBA
Institute of Polymer Extrusion and Compounding

juergen.miethlinger@jku.at
http://www.extrusion.jku.at

Research Focus

- Large-Scale Production Systems
- Production Systems for Individualised Needs
- Experimental Process Analytics
- Raw Material Resource Independence
- Energy Independence

Vision

Four long-term paradigms trigger a far-reaching transformation the European manufacturing industry has to undergo: (i) Factory and environment - green and sustainable, (ii) factory as a good neighbour - close to employees and customers, (iii) factories in the value chain – collaborative and (iv) factory and human beings - human centred (see European Commission, FACTORIES OF THE FUTURE, Multi-annual roadmap for the contractual PPP under Horizon 2020, Luxembourg: Publications Office of the European Union 2013, ISBN 9789279312380).

Following the European Manufacturing Vision 2030 the Institute of Polymer Extrusion and Compounding will focus in response to these megatrends on the one hand on polymer processing technologies for (i) **Large-Scale Production Systems**, (ii) **Self-Optimizing Production Systems**, (iii) **Hybrid Production Systems** and (iv) **Production Systems for Individualised Needs** and on the other hand on (i) **Continuum Modelling**, (ii) **Reduced-order Modelling** and (iii) **Experimental Process Analytics** for improving polymer processing technologies.

Thus, we aim to **increase the utility of polymer products with a sustainable economic and environmental benefit**. We train students to master polymer processing technologies theoretically and practically while making careful use of our natural resources in order to preserve them for next generations. Our credo "Smart(er) Polymer Processing Technologies for Resource-efficient Production and Products" includes particularly (i) **Raw Material Resource Independence**, (ii) **Energy Independence** and (iii) **High Skilled Jobs** as well as (iv) **Economic Wealth**.

According to our maxim "Resource Efficient and Cleaner Production and Products" we combine the increase of production and resource efficiency and the development of products that both meet the principles of eco-design and realise their full process and material potential. Therefore, we work on production processes such as multi-layer, multi-component, hybrid, and lightweight structures with thermoplastic matrix as well as on the reduction of environmental pollution, energy and material intensity, and the optimization of and research on efficient recycling technologies.
The material systems currently available for polymer processing are basically subdivided into the categories **thermoplastics**, **thermosets**, and **elastomers**. Thermosets achieve a weight-referred performance that comes close or even outreaches the performance of light-weight design with metallic materials. However, a considerable disadvantage is the effortful and time-consuming processing of thermosets. Thermoplastics, in contrast, allow superior process efficiency that enables manufacturing of high numbers of products but do not reach the mechanical performance of thermoset fibres reinforced composites. Combining the benefits of material aspects and processing routes of thermoplastics and thermosets would obviously be an advantage. The vision for **polymeric hybrid structures** is the provision and realization of a **single-stage process** that is as efficient as thermoplastics processing and at the same time, the resultant products might reach a performance that comes close to thermoset fibre reinforced composites. Within the scope of distinct technology development there already exist some respectable achievements with material systems that combine benefits from composite technology and thermoplastic processing. Here it is worth to mention direct compounding and subsequent processing of long glass fibre reinforced thermoplastics and manufacturing of products with the utilization of thermoplastic composite laminates with already consolidated fabrics. However, only little fundamental research was performed on material conceptions and on single-stage processing approaches that have to be assigned to the transition region between the processing of thermoplastics and the processing of thermosets. Hence, the fundamental scientific problems in that field have to be considered unresolved up to now. The primary challenge is to achieve wetting and consolidation of various solid components within a single-stage process in order to end up with a sophisticated polymeric hybrid structure.

With new and innovative polymer processing technologies for new and current materials the production of novel polymeric products should be achievable like (i) in the field of civil engineering e.g. **highly durable and sound-absorbing sewage pipe** systems for buildings, **high-strength water distribution pipe** systems with **integrated intelligence** e.g. sensors for water quality or mechanical load of the pipes, (ii) in the field of mobility e.g. **high-strength pultruded thermoplastic lightweight constructions**, (iii) in the field of packaging e.g. **recyclable down-gauged high barrier films** with excellent optics produced from renewable materials, and (iv) in the field of medicine e.g. new biologically stable or contrary absorbable **micro tubing concepts for blood pressure machines, capillary drain lines**, or **central and peripheral nervous system repair**.

The future possibilities of mechatronic components will help **in- and online process measuring goals** like flexibility and timesaving when at the same time keeping processes stable, improving quality requirements, and even increasing the efficiency of used resources. These developments support the investigation in (i) **Large-Scale Production Systems**, (ii) **Self-Optimizing Production Systems**, (iii) **Hybrid Production Systems** and (iv) **Production Systems for Individualised Needs**.

Approach

Polymer materials have been and will be the source of new technologies and innovative products. The morphological structure development and the property profile strongly depend - like for no other material group - on the processing technologies. Our focus on reducing raw material and energy intensity will include (i) multilayer structures, (ii) multi-component and hybrid structures, (iii) oriented and self-reinforced macromolecular materials, (iv) renewable raw materials, (v) novel additive manufacturing technologies like extrusion deposition modelling and (vi) improved extrusion and compounding performance.

Large-Scale Production Systems: As well-established process technologies that have been developed and optimized over the past decades extrusion and compounding have become key technologies in the polymer and other industries (e.g. pharmaceutical or food). Large-Scale Production Systems used in the production of films, pipes, or profiles show high potential in both resource and energy efficiency. By developing and implementing e.g. new plasticization concepts for processing renewable materials sustainable aspects could be achieved in the future. By using e.g. applied elongational rheology, in- or online implemented, with consideration of viscoelasticity or wall slippage, finally significantly improvements during processing such as avoiding material degradation effects or increased colour quality are possible. Furthermore, new scale-up models with e.g. consideration of specific production parameters like mixing, venting or the chemical conversion for reactive materials will shorten the research and development and also the time-to-market process.

Self-Optimizing Production Systems: Moreover, we will focus on self-optimizing plant concepts for e.g. fast ramp up, increased precision of product quality, and semi-autonomous plant operation as well as the necessary experimental and computational process analytic concepts. These systems require various different measuring and control devices, e.g. surface detection, NIR, or ultrasonic systems in addition to the necessary process know-how and for specific requirements model based control systems. The concept of a self-optimizing model based system is rather new in polymer production e.g. in pipe or profile extrusion. Thus, the prospect for innovation is significant. A desired higher degree of automation offers excellent economic advantages, since better efficiency reproducibility, and quality can be achieved. Further benefits include an easier operation of the whole production line and relieving strain on line workers.

Hybrid Production Systems: Classical composites with fabric reinforcement are manufactured mainly using thermoset processing methods that have the disadvantage of long cycle times. These processes are thus inappropriate for large scale manufacturing. To end up despite of that difficulties with innovative load bearing lightweight structures, it is necessary to modify the throughput intensive processing approaches for thermoplastics, e.g. multi-layer or multi-component extrusion, in a fashion that enables fabric reinforcements to be integrated in a short cycle time, or at high processing speed, respectively, and with no fibre damage. In the transition field between textile engineering science and polymer engineering science, only little fundamental research work was performed in the past. Therefore, the corresponding technologies are in early stages. The main challenges are the supply with semi-finished reinforcements suitable for the processing, the handling of the reinforcement without any damage, the precise placement and appropriate fixation of the reinforcement in the mould and the wetting of dry fibre reinforcements with thermoplastic materials. Further approaches are new concepts for the production of high molecular weight, highly oriented or also self-reinforced extruded structures.

Production Systems for Individualised Needs: Automated rapid production technologies for individual designed products are already available today. These rapid manufacturing processes show high potential for lot size one or small lot production. As they do not require any mould or die, product design changes can be executed quickly and easily at low cost. However, surface precisions and mechanical performance limit the industrial applicability. Manual refinishing often are necessary and the rapidly produced parts are only used for design reasons not as structural components due to their low tenacity. Challenges of improvement are output amount, mechanical product performance, surface precision, and online quality control. We emphasise on direct extrusion deposition for rapid production technologies without the need of a polymer filament for a broad range of processing in terms of materials usage, extrusion die concepts, or output ranges.

Continuum Modelling: An important research task in extrusion technology is the consideration of viscoelastic material behaviour in co-extrusion. Up to now most simulations consider non-isothermal and shear thinning effects but neglect layer-to-layer non-uniformities, flow instabilities, or other memory effects. Of further interest are new approaches to better predict the fibre degradation in plasticization units and fibre orientation in semi-finished products. For 3D simulations an elaborate pre-processing of the geometry by means of 3D-CAD has to be performed. This can be remedied by parameterized geometry generation even for complex parts like flat dies, pipe heads or extruder screws. Using the Volume-of-Fluid method also major deformations or free boundary conditions, which are often present in polymer processing, can be considered. This "free surface modelling" must also be refined. For process simulations of chemo-rheological reactive materials the reaction kinetics has to be linked to the conservation equations of mass, momentum and energy. FEM, FDM, BEM, FVM, DEM are well known. Further research directions will be to redirect the decision, which numerical solver is applied from the user to the simulation tool. Finally, we aim to provide solutions for inverse problems for accounting for the above mentioned multi physical effects and for recalculating optimized machine and tool geometries as well as quality

Reduced Order Modelling: Fast and stable codes applying semi-analytical models to the areas of polymer flow or heating and cooling processes are requested for real time control systems, which are customized and experimentally verified. Such modelling may either be done preferably by dedicated and mostly custom made Semi-Analytical models but, depending on processor power, also by commercial or freely available CFD tools. Both of them have their advantages and handicaps. Nevertheless, for any field of production it is desirable to implement the academic knowledge concerning to the production system directly, which at least can show the dimension and direction of system values or provide production parameters in highest available speed as it is needed for real time actions in extrusion and compounding lines like model based control concepts.

Experimental Process Analytics: Process analysis is indispensable. The measuring methods distinguish from offline to inline analysis of the process and finally of the product. To detect the influence of specific process parameters like temperature, pressure, and residence time on the product quality near infrared- and fluorescence spectroscopy is used e.g. in order to locate the chemical conversation when processing reactive materials. One of the most essential properties is mixing and melting in polymer extrusion systems. Therefore, tomographic or spectroscopic methods, e.g. ultrasound, terahertz, Raman, have been invented to detect particle and temperature distribution in the cross section of the barrel. Non-destructive sensing and imaging of the inner structure of materials is essential, for quality control and the development of new materials. One emerging optical imaging method, which allows the acquisition of cross-sections in a non-destructive and contactless manner, is optical coherence tomography which will be also used for in- and online process analytics in polymer extrusion and compounding applications

For some of the measurement and process principles mentioned above a close cooperation of the three mentioned Institutes, Institute of Polymer Extrusion and Compounding, Institute of Measurement Technology respectively Institute of Process Engineering, has proven to be successful and novel techniques are being explored and developed.

Impact

According to our maxim "Resource-efficient and Cleaner Production and Products" (i) the increase of production and resource efficiency, (ii) products that both meet the principles of eco-design and realise their full process and material potential by using production processes such as multi-layer, multi-component, hybrid, and lightweight structures with thermoplastic matrix and (iii) the reduction of environmental pollution, energy and material intensity, and (iv) efficient recycling technologies will have various substantial effects.

The scientific impact is deeper understanding of fundamental principles e.g. of the **transport phenomena in screw processing** related to **improved mixing** and **plasticizing performance**, **multi-layer and multi-component flow in extrusion dies** for the production of light-weight structures, **renewable raw material processing** and **recycling**, in- and online process analytics for novel **process automation concepts** and **plant self-optimization**, new **single-stage processing technologies** with less energy consumption and new material process ability, new machine concepts with increased reliability and durability, **new additive manufacturing methods** for enhanced product performance, **reversible multi-physic simulation methods**, **free surface numerical simulation**, **3D simulation with automatic pre-processing**, of **real-time simulation for model based control concepts**, and finally new concepts to increase utility and value of polymeric systems.

The technological and industrial effect is new **large-scale as well as individualised automated lot size one production technology** of multi-layer, multi-component, hybrid, and lightweight structures which help to increase the production and resource efficiency as well as to exploit the unique product properties.

The economic and social impact is the reduction of material, energy and pollution intensity, efficient waste-to-value networks, new developments e.g. for mobility, civil engineering, packaging, lightweight construction or medicine, but also high skilled jobs, and economic wealth.

References

[1] G. Gerstorfer, A. Lepschi, J. Miethlinger and B. Zagar: "An optical system for measuring the residence time distribution in co-rotating twin-screw extruders", in Journal of Polymer Engineering, Vol. 33, pp. 683-690, ISSN: 0334-6447, 11/2013.

[2] M. Aigner, T. Köpplmayr, C. Kneidinger and J. Miethlinger: "A network-analysis-based comparative study of the pressure/throughput behavior of polymer melts in barrier screw geometries", in Polymer Processing Society: Proceedings of the Polymer Processing Society 29th Annual Meeting, Proceedings of the Polymer Processing Society, Vol. 29, 7/2013.

[3] C. Kneidinger, G. Zitzenbacher, J. Miethlinger and G. Steinbichler: "New approach in the characterization of the melting process in single screw plasticizing unity using a model experiment", in Polymer Processing Society: Proceedings of the Polymer Processing Society 29th Annual Meeting, Proceedings of the Polymer Processing Society, Vol. 29, 7-2013.

[4] T. Köpplmayr and J. Miethlinger: "Application of the Network Simulation Method to Flat Dies with Inverted Prelands", in Polymer Processing Society, in International Polymer Processing, Vol. 28, pp. 322-330, ISSN: 0930-777X, 7/2013.

[5] T. Köpplmayr, I. Milosavljevic, M. Aigner, R. Hasslacher, B. Plank, D. Salaberger and J. Miethlinger: "Influence of fiber orientation and length distribution on the rheological characterization of glass-fiber-filled polypropylene", in Polymer Testing, Vol. 32, pp. 535-544, ISSN: 0142-9418, 2013.

[6] J. Miethlinger and M. Aigner: "Extrusion von Ethylen-Vinylalkohol-Copolymeren", in VDI: Extrusionstechnik 2013 Herstellung von Barrierefolienverpackungen, in VDI-Jahrestagung, 6/2013.

[7] V. Putz, I. Burzic, J. Miethlinger, F. Maier and B. Zagar, "Adaptation of In-line Ultrasonic Velocimetry to Melt Flow Measurement in Polymer Extrusion", in Measurement Science and Technology, Vol. 24, No. 10, IOP, 10/2013.

Competencies

The Institute of Polymer Extrusion and Compounding carries out fundamental and applied basic research and on the application of new polymer materials or new polymer processing technologies with an international interdisciplinary research team. Founded in 2010, we already refer to an extensive appropriate academic network with universities like UNIVERSITY OF LEOBEN, NATIONAL TECHNICAL UNIVERSITY OF ATHENS or VIENNA UNIVERSITY OF TECHNOLOGY and research institutions like AUSTRIAN CENTER OF COMPETENCE IN MECHATRONICS or WOOD K PLUS. We publish in international scientific journals, international conferences and carry out our projects often within the framework of public funding.

Our research collaborations primarily comprise **leading industrial companies of plastics machinery, plastic processing, and plastic raw material production** like BATTENFELD-CINCINNATI, BOREALIS, EREMA, GREINER, INTERNORM, KRAUSS-MAFFEI, LEISTRITZ, LENZING, MAPLAN, OERLIKON, POLOPLAST, SML, STARLINGER, TEUFELBERGER and TIGER COATINGS.

The Institute of Polymer Extrusion and Compounding may refer to **most modern equipped laboratories** for (i) **Simulation**, (ii) **Polymer Processing**, (iii) **Material Characterization**, and also for (iv) **Polymer Welding** and (v) **Extrusion Deposition Modelling** e.g. with single screw extruders with additional sensors (19/33D, 3x25/18D, 35/24D, 2x35/34D, 45/28D, 45/41D, 60/33D), co-rotating parallel twin-screw extruders (27/24-40-48D and 25/40D with several gravimetric feeders, underwater and strand pelletizing) and counter rotating conical twin screw extruder 50, a variety of on- and inline shear and extensional rheometers, different polymer welding methods, direct extrusion deposition modelling, sophisticated, industry like coextrusion lines for pipes, sheets and profiles as well as computational fluid dynamic tools.

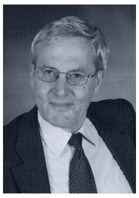
Proponents

Univ.-Prof. DI Dr. Jürgen Miethlinger MBA
Institute of Polymer Extrusion
and Compounding

juergen.miethlinger@jku.at
http://www.extrusion.jku.at

Univ.-Prof. DI Dr. Bernhard Zagar
Institute of Measurement Technology

bernhard.zagar@jku.at
http://www.jku.at/emt



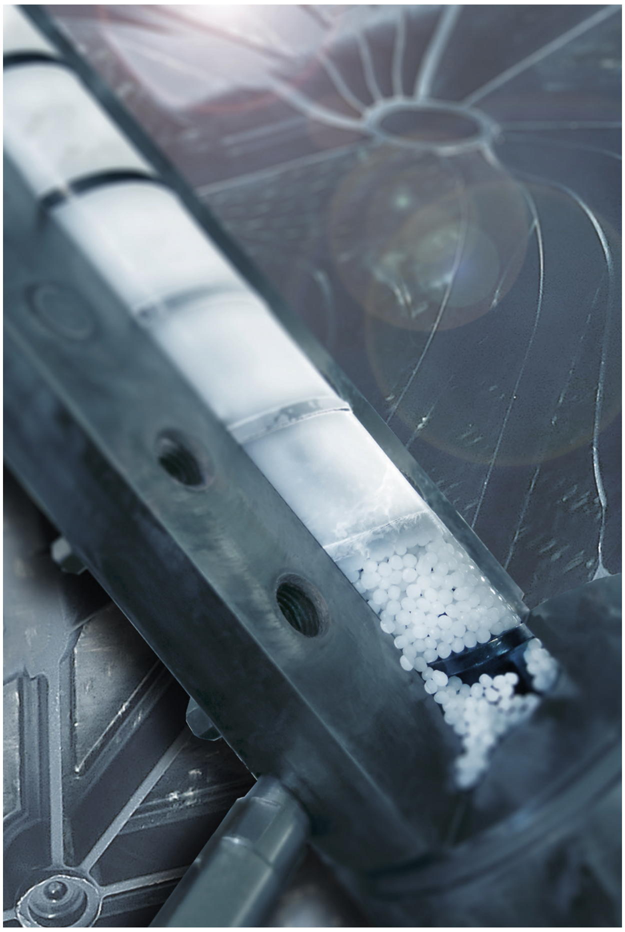
O.Univ.-Prof. DI Dr. Wolfgang Samhaber
Institute of Process Engineering

wolfgang.samhaber@jku.at
www.jku.at/ivt

Keywords

Polymer Processing, Measurement Technology, Process Engineering, Screw Extrusion Performance, Process Analytics, Applied Rheology, Computational Fluid Dynamics, Reinforced Pipes/Sheets/Films/Profiles/Compounds, Direct Extrusion, Natural Fibre Composites, Recycling, Fused Deposition Modelling

Polymer Injection Moulding and Process Automation



"Polymer injection moulding today has reached a major commercial relevance in application areas like automotive industry, teletronics, packaging and medical products. New business can be created by integrating more functions into smart products and combining the 3D shaping potential of injection moulding with endless fibre reinforcement for lightweight composites."

Georg Steinbichler

Focus Line 2:

Smart(er) Products and Production Processes

Coordinator:

Univ.-Prof. DI Dr. Georg Steinbichler
Institute of Polymer Injection Moulding and Process Automation

georg.steinbichler@jku.at
http://www.jku.at/ipim

Research Focus

- Value Added Manufacturing of Smart Polymer Products
- Utilization of Process Simulation and Virtual Machines
- Improve Plasticizing Units and Mould Cooling with Simulation and New Measurement Equipment
- Process Technologies for Energy Efficient and Automated Production of Lightweight Thermoplastic Fibre Reinforced Composites

Vision

Shortage of oil resources, political targets for CO2 reduction and heavier drive components in electric vehicles are demanding for **weight reduction** of automotive components for affordable mobility. With 100 kg of mass reduction a **fuel efficiency** gain of 0.4 -0.5 l/100 km can be achieved.

Our vision is to reduce weight in automotive applications with thermoplastic endless fiber reinforced composites. This material class shows a high **lightweight potential** and promises fast production times. Furthermore the recyclability contributes to the **overall sustainability** and the possibility of functionalization reduces processing steps significantly.

Our contribution is in **deep process understanding** and **optimisation** as well as **bionic tailoring of the structures**. In injection moulding product and production engineering our focus is on (I) improving the **overall energy efficiency** of the injection moulding process as well as to (II) integrate subsequent production steps into a one step production. Examples for (I) are increased efficiency in the plasticizing units heating system on the one hand and the cooling system of the mould on the other hand. By integrating several subsequent production steps into a single process we obviously will increase the energy efficiency of the manufacturing process, but equally important it enables us tailor properties of the product for a relatively low number of manufactured parts. An illustrative example of (II) can be found in the field of pharmaceutical drug delivery systems. In recent decades, several polymers have been specially designed to enhance the solubility and thus the bioavailability of the Active Pharmaceutical Ingredient (API). These polymers (carrier matrix) together with the dispersed API form a so-called polymer drug delivery system. To prepare pharmaceutical delivery systems, several techniques, such as spray drying, freeze drying, supercritical fluid drying and hot-melt extrusion, are available. The subsequent multistep procedure, which includes steps such as milling the pellets and pressing them into tablets to obtain the final dosage form, is complex and thus somewhat inefficient and costly. The commercial production of drug delivery systems by injection moulding will certainly lead to a **simpler and cleaner process** in which drug dosage forms can be obtained in only **one step**. In the production of packaging for food, beverage or pharmaceutical industries typical process steps are the extrusion of multi-layer films with a subsequent thermo-forming process. In certain cases applications it may be possible to replace this two step process by a co-injection moulding process where the pakkaging is manufactured from a shell component (e.g. Polypropylen) and a core component (e.g. EVOH) with certain barrier properties. Furthermore, our vision is the development of robust and precise measurement systems for a better understanding of the plastification process in injection moulding machines. Novel **condition monitoring systems** for the detection of machine defects (e.g. measuring the wear in the tribo-mechanical system barrel/screw) will reduce energy costs and periods of machine inactivity for inspections.

Approach

The main approach is to meet **industry demands** and therefore a tight cooperation with industry partners is important. The focus is on the computational modeling of processes and of the mechanical behavior of structures to reduce development times of real life processes.

For example we are developing models for the reactive polymerisation during injection to improve process equipment and reduce cycle times. Computational, bionic tailoring of structures enables the improvement of mechanical properties of the end product.

To combine various production steps into a single process the requirements on this process are increased. To meet this demands we analyze and improve the components of injection moulding process in cooperation with our project partners. To tailor the properties of moulded parts it is of utmost importance to understand and improve the **mixing and compounding performance** of single screw plasticizing units. For example, the production of pharmaceutical dosage forms: the distribution homogeneity of the drug in the polymer matrix must be ensured by the end of the injection moulding process. This is necessary to provide the same drug content and respective activity in each pharmaceutical dosage form. Therefore, the distribution analysis of API in the cavities of the mould and in the antechamber of the plasticizer unit is necessary. To ensure a trouble free production of packaging with low cycle times on the one hand and the high quality demands in food, beverage and pharmaceutical industries on the other hand it is important to analyse melt flow in hot runner systems and mould cavities. A major aspect in these research fields is the usage of **computational fluid dynamics (CFD)** to analyse the melt flow and heat transfer in the plasticizing unit and the mould. In combination with condition monitoring to both validate CFD results and generate a deeper understanding of the process we use the results of the CFD simulations for **DOE (Design of experiment)** studies to reduce experimental efforts. For the experimental verification of numerical and analytical simulations we developed inexpensive and easy-to-install ultrasound based systems for condition monitoring. Unknown quantities (temperature in screw ante-chamber and screw channel, solid bed ratio along the screw, screw and barrel wear) are evaluated using our fast systems.

Since high shear rates and viscous heating can occur during injection moulding (especially upon injection of the melt into the mould), the **rheology** of the polymer-drug system to be processed as well as the thermo-physical parameters (degradation and residual time of the API) must be well understood in advance.

Impact

Recent developments in the field are very promising. New cars with light weight designs are showing first examples for **future-oriented application** of **composites** and **thermoplastic materials** in the automotive industry.

The processing of **drug carrying polymers** using injection moulding technique along with process simulation play a key role in the improvement of the resulting tablets solubility. This in turn, will certainly contribute for the implementation of more **cost-effective production technologies** within the pharmacy industry, allowing yet for the efficient development of gender-targeted medications.

The results of our condition monitoring systems are important for the validation of numerical simulations, a better understanding of the plasticizing process and can be used for the input of a novel temperature control systems for the improvement of the final part quality. Furthermore, the prediction of the screw and barrel wear can significantly **reduce the cost-intensive inspection time** from hours (or days) to minutes.

With our research we will actively contribute to the material class as well as manufacturing processes of the 21st century.

References

T. Rettenwander, M. Fischlschweiger, G. Steinbichler, Computational structural tailoring of continuous fibre reinforced polymer matrix composites by hybridisation of principal stress and thickness optimisation, Compos Struct 108 (2014) 711–719.

J. Nagy, L. Reith, M. Fischlschweiger and G. Steinbichler, Modeling the influence of flow phenomena on the polymerization of ε-Caprolactam, Chem. Eng. Sci. (2014), http://dx.doi.org/10.1016/j.ces.2014.02.020, in press

K. Straka, B. Praher and G. Steinbichler, "Analyzing Melt Homogeneity in a Single Screw Plasticizing Unit of an Injection Molding Machine": Proceedings of the 11th International Conference of Numerical Analysis and Applied Mathematics, 21-27 September 2013, Rodos, Serie AIP Proceedings, Vol. 1558, 2013

B. Praher, K. Straka and G. Steinbichler, An ultrasound-based system for temperature distribution measurements in injection moulding: system design, simulations and off-line test measurements in water, Meas. Sci. Technol. 24 (2013), 084004

H.R. Juster, K. Straka, G. Steinbichler: "Simulation of pharmaceutical solid dispersion during injection moulding by using numerical (CFD) methods"; Poster-Presentation, Polymer Processing Society Conference (PPS 29), July 2013, Nürnberg, Germany

Competencies

As a research institution we are publishing our scientific output in widely recognized journals and at international conferences. Our research is well **interwoven** with **national research funding**, **universities** and **companies** in the field. A network of manufacturing, scientific community and industrial application is integrated in our research programs (e.g. APMT, PharmaMould, SolPol, CompTool projects). We have an **international research team** from all over Europe with an **interdisciplinary background**

Proponent

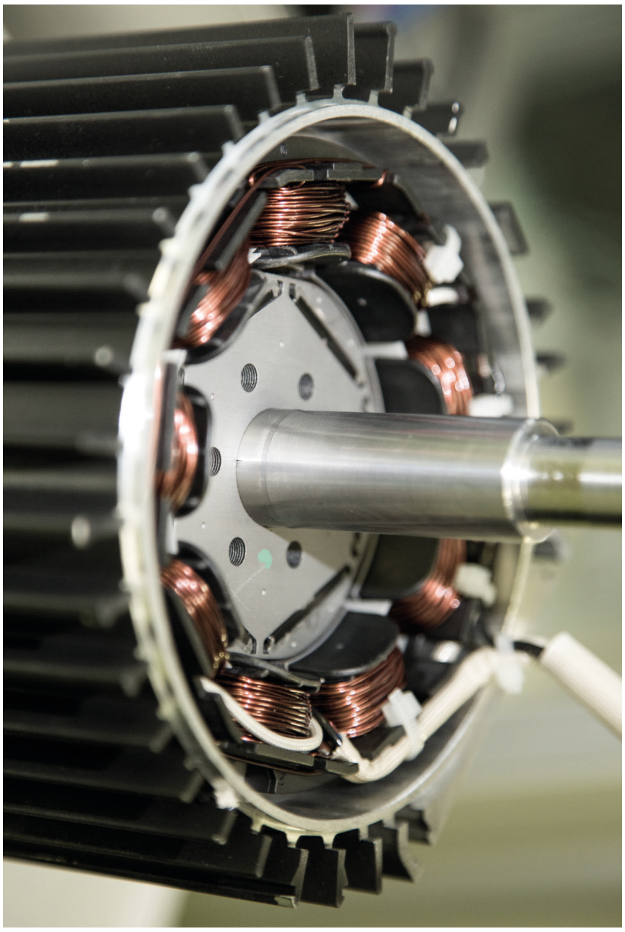
Univ.-Prof. DI Dr. Georg Steinbichler
Institute of Polymer Injection Moulding and Process Automation

georg.steinbichler@jku.at
http://www.jku.at/ipim

Keywords

Polymer Processing Technologies, Polymer Injection Moulding, Process Automation, Light Weight Design, Polymer Composites, Mould Cooling, Reaction Injection Moulding, Bionic Tailoring, Mixing and Compounding Performance of Single Screw Plasticizing Units, Computational Fluid Dynamics (CFD), Condition Monitoring

Drives' & Actuators' in Production Research



"The major paradigm change is that they behave like intelligent individuals which do not get just low level information from the control device, but orders what to achieve."

Wolfgang Amrhein

Focus Line 2:

Smart(er) Products and Production Processes

Coordinator:

O.Univ.-Prof. DI Dr. Wolfgang Amrhein
Institute of Electric Drives and Power Electronics

wolfgang.amrhein@jku.at
http://www.eal.jku.at/

Research Focus

- "intelligence", realized via powerful controllers, communication devices, software, flexible, robust actuator hardware
- "mechatronization" of actuators
- Standardization of interfaces
- formal modeling of actuator components

Vision

In future cyber-physical systems, drives and actuators (further on only the word actuator will be used) as individual components or as actuator systems will play a more complex, multifunction role than today. Their functions, interactions with other actuators in an actuator system, their control, level of autonomy, communication among each other, with sensors, and with higher level system control, their design, maintenance, lifetime assessment, disposal or recycling, will be strongly influenced by the requirements of **cyber-physical systems** and their **high complexity**. In order to facilitate the effective and efficient development of such systems, actuators will have to fulfill several additional requirements. The major paradigm change is that they **behave like intelligent individuals** which do not get just low level information such as reference signals of, as say a position, force, or fluid flow, from the control device, but orders what to achieve within, e.g., a certain time frame, or general rules in which way a certain process is to be actuated for optimal overall performance. Such orders are given in higher level general formal languages and may address also groups of actuators which share a joint task. Their actual task sharing is not specified by the supervisory control system but is **"negotiated"** by the **actuator group**.

In order to facilitate such type of operation, actuators need to know about each other concerning each group member's abilities, integrity statuses, and behaviour via corresponding models. For these reasons the actuators have to be connected with fast data lines.

The development of such actuators and actuator systems, respectively, not only requires **"intelligence", realized via powerful controllers**, **communication devices**, and **software**, but also **flexible** and **robust actuator hardware**, the behaviour of which can be described by simple models in a wide operating range. The development of such hardware, controllers, automation and communication software is challenging and costly. Therefore, powerful yet cheap, flexible actuator technologies and concepts will be required. They must have the potential to be configured for different applications, preferably by the combination of existing components or, even better, just via software changes. Furthermore, for cases where such kinds of actuator configuration are insufficient to achieve the desired product properties, a fast development, manufacturing, and assembly of optimized actuator systems largely via powerful modeling, simulation, and optimization methods, is essential.

Approach

Generally speaking, the approach is characterized by the following items:
A further **"mechatronization" of actuators**; this means, a smarter advantageous integration of components from different disciplines, more on-board control, more software which has to be adaptive and reconfigurable.
The identification of most powerful actuation concepts, which have the capacity for a wide application range, yet a behaviour which can be equivalently described by rather simple formal, e.g., mathematical models.

Standardization of interfaces, particularly of higher level formal languages, also for the actuator models, by means of which actuators can play their more autonomous roles, as described in the VISION above; these languages must be augmented by easy to comprehend input and output syntaxes which allow non-experts to interact with the system and to allow certain software modifications or even changes.

The actuator system must have **on-board self-explaining capabilities** by means of which low level or non-experts can quickly and easily learn about it and get into a position to play a competent active role.

A consistent formal modeling of actuator components and systems; the models are not only used in their development but serve also as kind of software aliases of the actuator in all matters of planning, decision making, optimization or adaptation of the superior cyber-physical system. Like a human being understands the world via mental models, the cyber-part needs formal models to understand the physical parts.

The rigorous use of design optimization, in particular of multi-criteria design optimization; today's typical design criteria will have to be complemented by criteria for an advantageous behaviour in the cyber-physical system; one criterion is the easy adaptability in hard- or/and in software.

Impact

The realization of actuator components and systems, as sketched above, requires more interdisciplinary research. This concerns all relevant mechatronic disciplines, in particular the **software aspect** which must be dealt with in much more elaborate fashion. Up to now, it was mainly **controller software**, running on local or even central controllers, written in low level languages or in some more dynamical systems modeling languages such as Matlab/Simulink. In a cyber-physical system higher level languages which can describe models of the actuator and more general commanding and reporting, all in a way understandable with a lower level software and system expertise than today. But also the exploitation of powerful integrations of different actuation technologies, such as, for instance, electro-magnetic with hydraulic, will gain more importance, since all options to achieve much better performing actuators must be exploited in order to achieve the required properties for a use in a cyber-physical context.

Modeling and simulation need to be furthered. Hierarchical modeling, the systematic conformation of models at different hierarchical levels, the routine use of structural model information for **design assessment and optimization**, **automatic model generation** and **model checking** (e.g., of model consistency) will become inevitable tools. A further important aspect will be the consistent thinking in design and model families and its support by appropriate modeling techniques.

Economic and societal impacts

The ability of future actuators to be an intelligent sub-system which plays more the role of an agent than of a slave in the superior system, requires more **openness**. The actuator must be an open system, able to tell about itself in a comprehensive way even to non-experts. It becomes a glassy object, proprietary of those features which have been protected so far by hiding them, must be either given up or protected via patents. In the cyber-physical setting, the discovery of patent infringements becomes easier. All this requires modified or new business models, which probably need to be finally evaluated and adapted by trial and error.

Standardization of various typical interfaces will be a much more complex undertaking than today, since it has to involve much more parties and subjects and will be mostly a global undertaking.

New ways of co-operation between these many parties will become necessary. The high confidentiality in the product development phase must be weakened, but, may be, not fully given up. New kinds of partnerships for this phase must be found. They have to ensure the necessary broad competencies in terms of technological knowledge and clout but also the ability to enter the market successfully.

References

[1] H. Kogler and R. Scheidl: "Flatness Based Control of a Low Power Hydraulic Switching Converter for Linear Motion Control, in: Proc. of the Institution of Mechanical Engineers, Part I: Journal of Systems and Control Engineering, Volume Submitted for publication, 2013.

[2] R. Scheidl, B. Manhartsgruber and H. Kogler: "Mixed time-frequency domain simulation of a hydraulic inductance pipe with a check valve", in Proc. of the Institution of Mechanical Engineers, Part C: Journal of Mechanical Engineering Science, Vol. 225, No. 10, pp. 2413-2421, 2011.

[3] R. Scheidl and B. Winkler: "Model relations between conceptual and detail design", in Mechatronics, Vol. 20, No. 8, pp. 842-849, 2010.

[4] B. Winkler, A. Plöckinger and R. Scheidl: "A Novel Piloted Fast Switching Multi Poppet Valve", in International Journal of Fluid Power, Vol. 11, No. 3, pp. 7-14, 2010.

[5] S. Silber, J. Sloupensky, P. Dirnberger, M. Moravec, W. Amrhein and M. Reisinger: "High Speed Drive for Textile Rotor Spinning Applications", in IEEE Transactions on Industrial Electronics, Vol. 8, pp. 2990-2997, 2013.

[6] W. Amrhein: "Magnetic Bearing Systems for Low Cost Applications", in 1st Brazilian Workshop on Magnetic Bearings", Rio de Janeiro, Brazil, Oct. 25.-26, 2013, Keynote Speech.

[7] H. Mitterhofer, W. Gruber and W. Amrhein: "On the High-Speed Capacity of Bearingless Drives", in IEEE Transactions on Industrial Electronics, Vol. 8, pp. 3119-3126, 2013.

[8] W. Gruber, W. Briewasser, M. Rothböck and R. Schöb: "Bearingless Slice Motor Concepts without Permanent Magnets in the Rotor", in ICIT 2013, IEEE International Conference on Industrial Technology, Feb. 25-27, 2013.

Competencies

The involved institutes conduct research in electric and fluid power drive and actuator technologies. They co-operate routinely in overlapping issues, such as magnetic actuation of hydraulic valves, or integrated electro-hydraulic drive or actuation systems. Research topics are technological issues, such as new actuation principles, application of new materials, the consistent modeling and simulation of various relevant physical phenomena as a basis for model based component or system design and optimization, the application of mechatronic design paradigms and of advanced control concepts.

Both institutes are complemented by corresponding strong research groups of the Linz Center of Mechatronics (LCM), who focus on applied research in close cooperation with industry. The institutes and the related LCM researchers cooperate tightly and benefit from each other's competencies and expertise.

Internationally leading research is done in the fields, modeling and simulation of fast hydraulic processes, digital hydraulics and hydraulic switching control, fast switching and check valves, multi-criteria design optimization of electric and fluid power drives.

Co-operations with in many cases internationally leading companies of different branches, such as, Bosch, Bosch Rexroth, SIEMENS, SIEMENS VAI, Hoerbiger, General Electric, ENGEL, Magna, etc. on various topics proof the ability to direct research to practically relevant topics and to successfully transfer research results to practice.

Proponents

O.Univ.-Prof. DI Dr. Wolfgang Amrhein
Institute of Electric Drives and
Power Electronics

wolfgang.amrhein@jku.at
http://www.eal.jku.at/

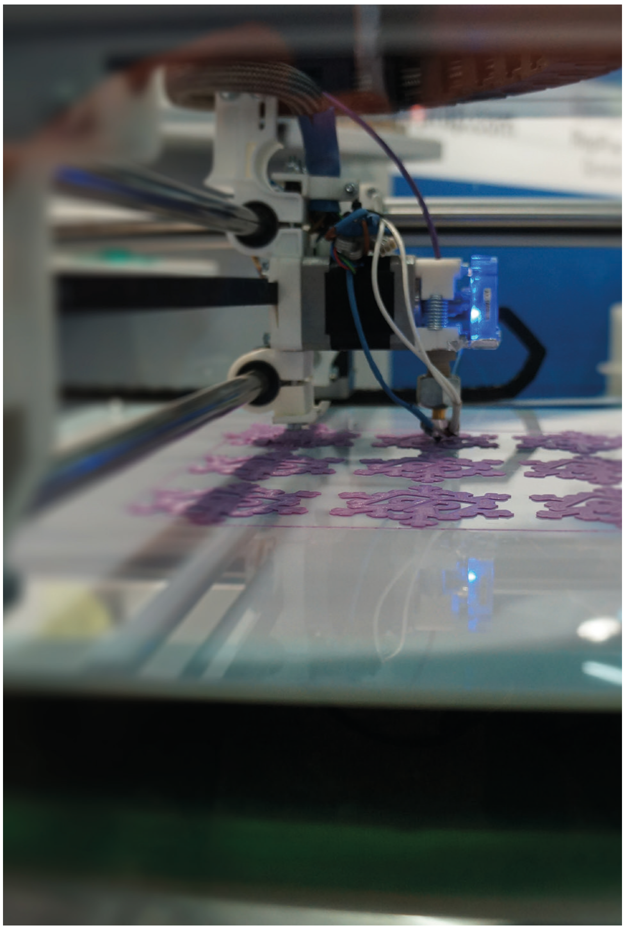
O.Univ.-Prof. DI Dr. Rudolf Scheidl
Institute of Machine Design
and Hydraulic Drives

rudolf.scheidl@jku.at
http://imh.jku.at

Keywords

Mechatronic Subsystems, Electric Drives and Actuators, Hydraulic Drives and Actuators, Autonomous Actuators

Evidence Based Innovation Policies for Additive Manufacturing



"All in all, the findings of our study will provide a rich empirical basis for the design of focused innovation policies targeted at tapping the potential of AM for pursuing large scale policy targets as formulated in the EU Horizon 2020 framework".

Matthias Fink

Focus Line 2:

Smart(er) Products and Production Processes

Coordinator:

Univ.-Prof. MMag.Dr. Matthias Fink
IFI - Institute of Innovation Management

matthias.fink@jku.at
http://ifi.jku.at/

Research Focus

- Additive Manufacturing
- Innovative Research Methods Through Online Media
- Disruptive Technologies
- Gamification

Vision

As early as 1984 Chuck Hull of 3D Systems Corporation presented the first working **Additive Manufacturing** (AM) system, which was commercialized only five years later. However, in spite of its practical importance within certain communities, AM, which is a "process of joining materials to make objects from 3D model data, usually layer upon layer […] manufacturing methodologies" (ASTM International, 2012), has only recently attracted greater attention of policy makers and the general public. One of the reasons for the successful establishment of AM in production processes is the possibility to use an extensive range of materials. **Materials** reach from **different polymers**, **ceramics**, **metals**, **composites** and **paper** to more experimental ones, such as **chocolate**, **sugar** and **concrete**. In spite of global recession the AM industry is expected to grow continually, accounting for a total sale of products and services of $3.7 billion by 2015. Current spectacular reports of organs, artificial meat and homemade weapons produced with AM gave impetus to euphoric predictions, e.g. that AM will open the door to a "new industrial revolution" and to a "democratization of manufacturing" (Anderson, 2013). Driven by these expectations, shares of leading companies in the AM industry, such as 3D Systems (DDD) or Stratasys (SSYS), showed an extraordinary rally. Likewise, national (e.g. US; China) and supra-national (e.g. EU; OECD) innovation policies have devoted significant resources to AM.

At the same time, voices get louder that question the bright future of AM as a panacea for economy and society (Citron Research, 2013). It is argued that AM as a technology is almost 30 years old and has still only established practical relevance in a limited number of small niches, such as Rapid Prototyping (RP) or the production of casting molds for industry, jewellery and dental applications. Key applications, such as the **production of artificial tissue** (Tissue Engineering), have remained at an experimental stage. All in all, the impact of AM on society has remained limited so far. Thus, it remains questionable if the past and **potential future effects of AM on society** justify the allocation of significant amounts of tax money on the further development of this technology. More specifically, as AM is a highly heterogeneous field of technology, the question arises, on which action fields innovation policy needs to focus and which action fields may be ignored.

Approach

In order to answer this question, **technology assessment** (TA), which aims at providing insights on new technologies and their likely societal consequences, is applied. While traditional TA (TTA) is an analytic activity, aimed at providing decision makers with an objective analysis of the effects of a given technology, TA has developed towards **constructive TA** (CTA), i.e. an interactive process including all stakeholders which does not only aim at anticipating future societal impacts of new technologies, but also at formulating policy interventions in order to influence the development path of these technologies. [1]

Results of TA are not only linked to the approach, but also sensitive to the groups among which it is conducted. TA which is conducted among experts who are actively taking part in the development of a new technology (community members) is able to anticipate future societal impacts of new technologies based on the experts' experience of path dependencies and their in-depth understanding of the interdependencies in the development process. Thus, TA results emerging from such expert communities are the most reliable prediction of the future impact of a new technology [2].

In contrast, policy makers typically neither have direct practical experience nor theoretical knowledge regarding new technologies [3]. In TA, they form their expectations based on information provided to them by others. However, the information provided by others is regularly influenced by the others' wish to promote the respective new technology [4]. Additionally, policy makers tend to be biased in their expectation about future events by their ideology according to framing theory [5] and they are interested in solving political challenges with simple solutions. Thus, compared to the experts, policy makers tend to overestimate the potential of new technologies regarding their potential contribution to meeting societal challenges.

The general public is the group that is less informed about new technologies. This lack of information on the features of new technologies also brings about a lack of knowledge on its potential effects [6]. Even if potentially affected positively, uninformed persons who do not have a conscious stake in the development process of a new technology tend to be conservative in their expectations regarding its contribution [4]. Thus, compared to the experts, the general public typically underestimates the potential impact of new technologies [7].

We collected data using an online questionnaire that is administered to these three. To identify the experts in the field of AM, we rely on the process of self-selection. It is most likely that the members of the biggest German-language online magazine (3Druck.com) on AM participate actively in the discourse regarding the development of this technology. Thus, in order to collect data on the perception of AM experts, we approach the members of this online magazine. For the collection of data among policy makers we approach all Austrian institutions that are involved in designing the regulative framework for AM and contact the members of these institutions who are concerned with innovation policy. The collection of data among the general public is based on a random sample drawn from the Austrian population using a digital register of households.

The analytic strategy for addressing the research question is a comparison of means between the target group subsamples employing Independent Sample T-test. This simple analytic strategy matches the early stage of this research field and reflects our integrative approach to TA, which strives for a comparison of the perceptions of the future potential of AM that emerged in a discourse among the stakeholders involved in the development of this

technology with the perceptions of policy makers and the general public on the status quo of this technology. We argue that our survey among experts provides a snapshot of the ongoing CTA, while the survey among policy makers and the general public follows the logic of TTA and thus reveals the respondents' perceptions of the potential effects of AM as a given technology. By linking the outcomes of both approaches to TA, which were undertaken simultaneously, we can mutually compensate for some of their major shortcomings. Taking the results of the CTA as a reference, we overcome the limited capacity of TTA to fulfil an early warning function due to a lack of involvement in the evolution process of the new technology, but at the same time account for the value of an outside perspective that avoids insider blindness by redirecting the focus to the major political and social picture. We compare the perceptions of experts to those of policy makers to identify need for action regarding the allocation of public funds. Likewise, we compare the perception of experts with those of the general public to show the need for action regarding the establishment of a public opinion on AM that serves as a democratic legitimization for innovation policies in the area of AM.
As AM is a highly heterogeneous field of technology in itself, the analysis is done on two levels of detail. First, we compare the perceptions on the level of the Large Scale Targets, (i.e. Employment, R&D and education, Environment, Poverty and social exclusion) as formulated in the EU Horizon 2020 Strategy to identify the action fields for innovation policies which aim at tapping the potential of AM. Second, we dig deeper into the specific policy goals in order to be able to formulate concrete action points. The analysis enables us to draw up an agenda that informs policy makers on which action fields innovation policy needs to focus and which action points need to be taken.

Impact

The results of this research will provide several contributions on the theoretical and practical level. First, the development and application of an **integrative approach to TA** that can reduce the major shortcomings of an isolated use of TTA or CAT contributes to a much needed further development of the methods in TA. Second, the detailed empirical picture of the divergences of expectations in a new technology such as AM between major groups of society will show the tension which needs to be accounted for in the design of feasible innovation policy. Third, for the field of AM, we will provide a policy agenda that offers concrete action points addressing these tensions. Finally, our approach to create **an evidence based agenda for innovation policy** using an integrative TA as introduced in this study may provide guidance for replications in other policy areas, geographical fields and new technologies.

All in all, the findings of our study will provide a rich empirical basis for the design of focused innovation policies targeted at tapping the potential of AM for pursuing large scale policy targets as formulated in the EU Horizon 2020 framework (European Union, 2014).

References

[1] J. Schot and A. Rip: "The Past and Future of Constructive Technology Assessment", Technological Forecasting and Social Change, Vol. 54, No. 2, pp. 251-268, 1996.

[2] I. Miles: "The Development of Technology Foresight: A Review", Technological Forecast and Social Change, Vol. 77, No. 9, pp. 1448-1456, 2010.

[3] D.H. Guston and D. Sarewitz: "Real-time Technology Assessment", Technology in Society, Vol. 24, No. 1-2, pp. 93-109, 2002.

[4] M. Fink, R. Lang and R. Harms: "Local Responses to Global Technological Change: Contrasting Restructuring Practices in Two Rural Communities in Austria", Technological Forecasting and Social Change, Vol. 80, No.2, pp. 243-252, 2013.

[5] A. Tversky and D. Kahneman: "The Framing of Decisions and the Psychology of Choice". Science, Vol. 211, No. 4481, pp. 453-458, 1981.

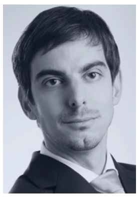
[6] B.-A. Lundvall: "National Systems of Innovation: Towards a Theory of Innovation and Interactive Learning", Pinter, London, UK, 1992.

[7] A. Lundström, P. Vikström, M. Fink, M. Meulemann, P. Głodek, D. Storey and A. Kroksgård: "International Comparisons of the Costs and Coverage of SME and Entrepreneurship Policy: Sweden, Poland, Austria, UK and the Flanders Region of Belgium", Entrepreneurship, Theory & Practice DOI: 10.1111/etap.12037, 2013.

Competencies

This research builds on a stream of research and publications by Matthias Fink on the social and economic impact of disruptive technologies (e.g. [4]) that was funded by several public research funds such as the Austrian National Bank (OeNB) and private initiatives such as netidee. The key, however, is the theoretical knowledge and practical expertise of Johannes Gartner, who is co-founder and CEO of a start-up company specialized in online development. He has also developed and is still running the biggest and most influential German-language online magazine on AM, which is called 3Druck.com. As disruptive technologies have a major impact on society and shift economic rents between social groups, such technologies also have far reaching legal implications. These legal aspects are covered by Daniela Maresch, with her extensive expertise in business and law.

Proponents



Univ.-Prof. MMag.Dr. Matthias Fink
IFI - Institute of Innovation Management

matthias.fink@jku.at
http://ifi.jku.at/

Mag. Johannes Gartner
IFI - Institute of Innovation Management

johannes.gartner@jku.at
http://ifi.jku.at/

Mag.ª Dr.in Daniela Maresch LL.M.
IFI - Institute of Innovation Management

daniela.maresch@jku.at
http://ifi.jku.at/

Keywords

Innovation Management, Innovation Policy, Additive Manufacturing, Technology Assessment

Optimal Design of Industrial Experiments

"In all these scientific fields, new methods will enable researchers to employ more complex and realistic models for their respective experiments and solve the design problems with reasonable effort. In all conceivable instances, better and more realistically designed experiments help to reduce costs and minimize errors."

Werner Müller

Focus Line 2:

Smart(er) Products and Production Processes

Coordinator:

Univ.-Prof. Dr. Werner Müller
Department of Applied Statistics

werner.mueller@jku.at
http://www.jku.at/ifas

Research Focus

- Developing Efficient Methods for Collecting Data in Industry
- Algorithms for Tailor Made Experimental Designs
- Simulation-based and Approximate Bayesian Computation Approaches
- Applications in Real Industrial Processes

Vision

Industrial experiments are the major source of information for quality improvements in production and services. The proper design of such experiments guarantees the efficient gathering of observations and is (other than in the inference stage) the only way of decisively increasing the quality and substance of the data. It forms an integral part of the so-called **Six Sigma** approach, an internationally established set of tools and techniques for process improvement which has become a paradigmatic approach in industrial production.

"In general, every machine used in a production process allows its operators to adjust various settings, affecting the resultant quality of the product manufactured by the machine. Experimentation allows the production engineer to adjust the settings of the machine in a systematic manner and to learn which factors have the greatest impact on the resultant quality. Using this information, the settings can be constantly improved until optimum quality is obtained." (quoted from www.statsoft.com [1]) Early statistical investigations about how to plan experiments efficiently originated almost entirely from agricultural problems, see the well-known pioneering monograph by Fisher (1935) [2]. Therein the emphasis is laid on detecting the influences of discrete factors leading to heavy use of combinatorial principles in the construction of the experimental designs (e.g. Latin squares, Balanced Incomplete Block Designs etc.). A whole branch of theory for categorical designs developed along these lines and one can find a vast number of publications devoted to it.

However, such designs are of limited use in the industrial setting, where the essential factors, the coordinates, are continuous rather than discrete (they may be still useful for some more specific problems). For classical regression relationships Box and Wilson (1951) [3] suggested the use of the in what followed so-called **response surface designs**. Therewith they initiated a school that proceeds to produce many results that are useful for industrial applications. Their aim is to develop standard designs (such as fractional factorials or central composite designs) for regularly shaped design regions in order to comply with a list of requirements for proper experimentation.

A different approach is adopted by the third large branch of experimental design theory, the so-called **optimum design of experiments** (o.d.e., predominantly put forward by Kiefer (1985) [4]). Here, the main construction principle for a well designed experimental plan is as follows. Asserting hypothesis-testing or parameter estimation as the aim of the experiment, the task remains to take a (possibly given) number of measurements in a way, that either the power of the test or the precision of the estimator is maximized. Additional requirements such as the unbiasedness of the statistical method, restrictions on the experimental conditions (e.g. to a certain experimental region), etc. usually enter as side-conditions of the maximization problem. The advantage of the o.d.e. approach is that it allows the application of computational algorithms for the construction of tailor-made designs.

This is of particular importance in the industrial applications where the experimental regions hardly ever are of regular shape and other experimental conditions frequently violate symmetry properties. Moreover, often do the designs obtained by running o.d.e. algorithms correspond very closely to those derived from combinatorial principles or practicability rules. Therefore, in our research we will mainly refer to results from o.d.e. theory, but the many parallels to the other two branches of design theory will be pointed out.

Since the pioneering monograph by Fedorov (1972) [5] there have appeared a number of book-length treatments on o.d.e. stressing various aspects of the theory and its applications.

A recent new approach to o.d.e. are **simulation-based optimal design** techniques. The goal is still to find the optimal configuration of factor settings with respect to an expected utility criterion. This criterion depends on the specified probability model for the data and on the assumed prior distribution for the model parameters and is now optimized by simulation techniques. We develop new simulation based optimal design methods which incorporate likelihood-free approaches and utilize them in novel industrial applications.

Approach

We are concerned with improving data collecting schemes via methods of optimum experimental design, which can be applied in cases where the experimenter has at least partial control over the experimental conditions. Furthermore we focus on cases where a probability model for the investigated phenomenon is not easily available and the situation lends itself naturally to simulation-based approaches in conjunction with a recently popularized simulation technique called **approximate Bayesian computing** (ABC).

The objective of optimum experimental design is to find the best possible configuration of factor settings with respect to a well-defined criterion or measure of information for a specific statistical model. The design criterion determines in which respect the solution to this optimization problem is "optimal." For example, D-optimality minimizes the determinant of the variance-covariance matrix of the parameters in a regression model. Other criteria might be related to minimizing prediction variance, efficient discrimination between different models, etc..

In **Bayesian experimental design**, a prior distribution is attached to the parameters of the statistical model. This prior distribution reflects prior knowledge about the parameters of the model. A criterion derived from the probability model may depend on the unknown parameters. In the Bayesian setting, however, it is natural to deal with such a criterion by averaging it over the parameter values with respect to the prior distribution. This naturally leads to a decision-theoretic approach to experimental design.

Here, the criterion of interest is computed for the posterior distribution of the parameters and then averaged over the marginal distribution of the data. The posterior distribution summarizes the knowledge about the parameters after observing the data. Thus, if the average criterion for the posterior distribution is at least as large as the criterion for the prior distribution, this reflects some notion of learning from the observations.

ABC is sometimes referred to as **likelihood-free method** and can be applied if simulating the data from the probability model is feasible for every parameter. The simplest case is likelihood-free rejection sampling. The goal is to sample from the posterior distribution. This is done by drawing the parameters from the prior distribution, drawing a variable from the probability model, and accepting this parameter if the variable is close to the real data. Thus, direct sampling from the posterior distribution is replaced by sampling from the prior distribution. The efficiency of this approach crucially depends on the similarity between the posterior and the prior distribution, i.e. the information gain of the posterior compared to the prior distribution.

We have implemented tentative versions of a basic **ABCD** (D for design) algorithms for an ordinary linear regression example, for which the exact solution is easily available, see e.g. Hainy et al. 2013 [6]. Our results show that this method is capable of delivering the right results and therefore may be useful. However, whether the computational burden is manageable crucially depends on the size and complexity of the problem at hand. Therefore, it will be necessary to develop refinements of this algorithm that would increase its applicability to a large spectrum of problems. These considerations demonstrate that approximate Bayesian computing offers a wide range of new opportunities for solving general Bayesian optimum design problems.

Impact

An important issue besides the development of new methods will be their **application in real industrial processes** for which no satisfying solutions exist as well as in design problems which do not necessarily require a simulation-based approach, but where simulation-based methods might provide a reasonable alternative. The goal of these applications will be to compare the simulation-based algorithms, their solutions and efficiency, to already existing solution methods.

Whether the optimal design is suitable for parameter estimation, prediction, model discrimination, finding the mode, hypothesis testing, etc., crucially depends on the choice of the utility function. Compound design criteria may be created by combining several criteria and weighting them according to their perceived importance. Since the **choice of the criterion** has a crucial impact, it is essential to apply the methods to different criteria in order to get a comprehensive picture of the methods.
Approximate Bayesian computing adds some degrees of freedom to the implementation of a sampler, in addition to the usual choices which have to be made in traditional Monte Carlo or MCMC sampling. The experimenter has to choose the form of the kernel function, tightness parameters or summary statistics. A choice which is optimal for one case is not necessarily optimal for another. Since these decisions have a significant effect on the performance of the ABC sampler, it is necessary to carry out some fine-tuning for each application.

Simulation-based approaches can be of great value to optimal experimental design whenever other methods fail to deliver useful results or are too inefficient. The use of ABC techniques further expands the range of possible applications to design problems that were intractable before. Therefore, by propagating these methods we will induce industrial partners and other researchers to construct optimal experimental designs for problems not thought of before. ABCD could become a standard solution method for classes of problems for which its application is indicated.

Potential applications of simulation-based optimal design besides industry include genetics, ecology, chemistry, physics, medicine (pharmacy), geography, and economics. In all these scientific fields these new methods will enable researchers to employ more complex and realistic models for their respective experiments and solve the design problems with reasonable effort. In all conceivable instances, better and more realistically designed experiments help to reduce costs and minimize errors.

References

[1]http://www.statsoft.com/Textbook/Experimental-Design viewed on 7.4.2014.

[2] R.A. Fisher, “The Design of Experiments”. Oliver & Boyd Ltd., Edinburgh,1935.

[3] G.E.P. Box and K.B. Wilson: “On the experimental attainment of optimum conditions (with discussion)”, Journal of the Royal Statistical Society, Series B, 13:1–45, 1951.

[4] J. Kiefer: “Collected Papers”, Springer, New York, 1985.

[5] V.V Fedorov: “Theory of Optimal Experiments”, Academic Press, New York, 1972.

[6] M. Hainy, W. Müller and H. Wynn: “Approximate bayesian computation design (ABCD), an Introduction”, in D. Ucinski, A. C. Atkinson, M. Patan (Eds.): “mODa 10 – Advances in Model-Oriented Design and Analysis”, Contributions to Statistics, Springer International Publishing, pp. 135-143, 2013.

[7] H. Dette and W.G. Müller: “Optimal designs for regression models with a constant coefficient of variation”, Journal of Statistical Theory and Practice 7 (4), pp. 658-673, 2013.

Competencies

The department of Applied Statistics at the Johannes Kepler University Linz is one of the few in the German speaking area offering a full bachelor and masters programme in Statistics. It host two internationally recognized reasearch groups in the areas of **Bayesian Statistics** and **Experimental Design**.

I personally also have a longstanding record in many areas of experimental design, such as for correlated responses, nonlinear models, nonparametric regression, etc as well has an expertise in spatio-temporal econometric techniques and applications and continuously contribute to the respective literature. I have lead a number of relevant internationally funded research project, such as since 2012, “Designs for Spatial Random Fields”, funded by ANR/FWF, and in 2004 - 2005, “Optimum design for correlated processes”, funded by FWF, jointly with the Department of Mathematics of the University of Klagenfurt.

In the past 10 years I spent long term research stays at the Isaac Newton Institute Cambridge UK, the University Nice/Sophia Antipolis, France, Glaxo-SmithKline, Philadelphia, USA, the Universidad de Salamanca, Spain and the University of Vienna, Austria.

I am editor of the journal **Statistical Papers** and on the editorial board of Spatial Statistics and the Austrian Journal of Statistics. I have been the vice-president of the **International Society of Industry and Business Statistics** (ISBIS) 2011-2013 and am since 2014 president of the **Austrian Statistical Society** (ÖSG).

Our research group has conducted a number of successful collaborations with partners in government and industry, most notably the Entschädigungsfonds für die Opfer des Nationalsozialismus and the voestalpine AG. Most recently an experimental design project undertaken for the Pöttinger Maschinenfabrik Ges.m.b.H. has led to the publication Dette and Müller (2013) [7].

Proponent

Univ.-Prof. Dr. Werner Müller
Department of Applied Statistics

werner.mueller@jku.at
http://www.jku.at/ifas

Keywords

Experimental Design, Simulation-based Design, Likelihood-free Methods, Six Sigma

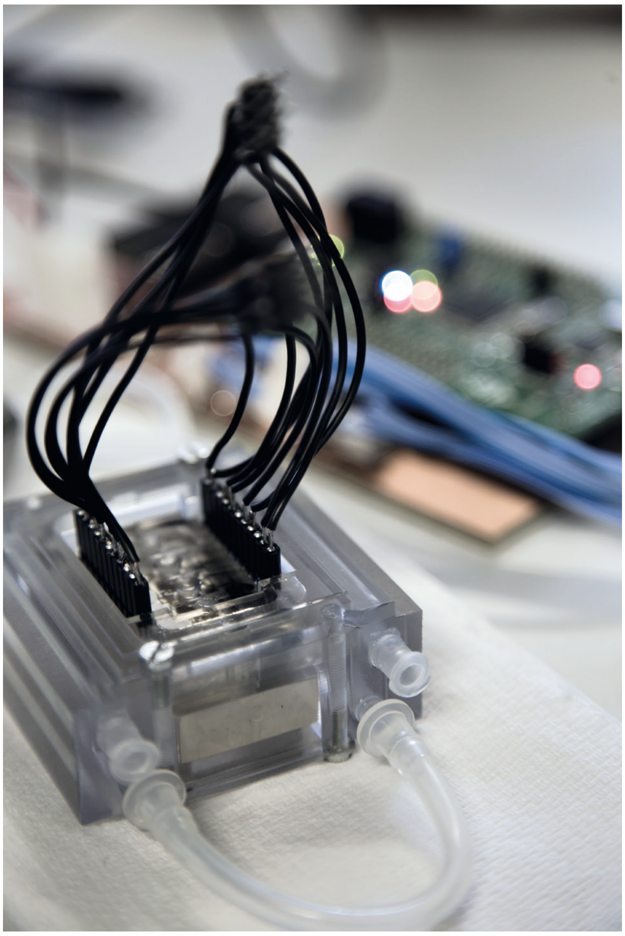
Focus Line 3:
Future and Emerging Enabling Technologies for Production Systems

FL3-01 **Signal Processing**, **Microelectronics and Sensors/Instrumentation**
Coordinators: Sepp Hochreiter - Institute of Bioinformatics, Mario Huemer - Institute of Signal Processing

FL3-02 **Next Generation Software Technologies: Smart Engineering for Systems of Systems**
Coordinators: Alexander Egyed - Institute of Software Systems Engineering, Paul Grünbacher - Institute of Software Systems Engineering

FL3-03 **Machine Perception as Supporting Technologies**
Coordinators: Gerhard Widmer - Institute of Computational Perception, Oliver Bimber - Institute of Computer Graphics

Signal Processing, Microelectronics and Sensors/Instrumentation



"Regarding research advances in signal processing, we see an expansion towards bio-inspired methods, cognitive systems which can sense the current environmental parameters relevant for operation and adapt to it, processing of large data sets ('Big Data'), and machine learning methods."

Sepp Hochreiter

Focus Line 3:

Future and Emerging Enabling Technologies for Production Systems

Coordinator:

Univ.-Prof. Dr. Sepp Hochreiter
Institute of Bioinformatics

sepp.hochreiter@jku.at
http://www.bioinf.jku.at/

Research Focus

- Physical Chemosensors, Ultra-sound-, Optical-, and Micro- and Millimeter Wave Sensor Systems
- Industrial Wireless Sensor and Actuator Networks
- Classical Signal Processing Methods, Processing of Massive Data, Virtual Sensors, and Machine Learning Techniques
- Micro- and Nanoeletronics

Vision

Two main pillars of technological progress in this area in the last decades are (i) **microfabrication technology** and (ii) **information theory**, both of which are heavily depending on each other. Since the early 1970's when the first integrated circuits appeared, the number of transistors on integrated circuits followed Moore's law and doubled approximately every 18 months, which today enables both, the processing of an enormous amount of data at very high speed and the storage of data in miniaturized devices at lowest cost. Making optimum use of this tremendous processing power and storage capability is the main topic of information theory, which was founded by C.E. Shannon in the 1940's. The continuously growing research community in information theory laid not only the theoretical foundations of all modern information and communication technologies (ICT) but also developed methods to reach basic boundaries within close limits. Together, both disciplines changed our world in a dramatic way, for which mobile communications may be referred to as one of the most prominent examples. Apart from still driving classical silicon-based integrated circuits towards its physical limits ("More Moore"), last years showed radically new research directions, like nanotechnology or soft-matter electronics summarized under the term "More than Moore". But still microelectronics will be the main enabler by delivering integration of these new technologies. In addition, the interaction between silicon-based electronic systems and optical, chemical and biological systems is a very active area of research from which radically new types of sensors and actuators are to be expected. Technologically this is partly based on microsystems (or MEMS) integrated on the same (silicon) platform. As an alternative, other microfabrication methods are employed for the non-electronic parts of such systems (including polymer technology) which, together with the microelectronic readout electronics are integrated in miniaturized hybrid systems. Regarding research advances in signal processing we see an expansion towards bio-inspired methods, cognitive systems which can sense the current environmental parameters relevant for operation and adapt to it, processing of large data sets ("Big Data"), and machine learning methods.

Based on current research paths, we envision sensors based on a variety of technologies ranging from classical silicon-based electronics to biological systems, all of which are functionally integrated and controlled by electronic circuits and are supported by digital signal processing to extract useful information from the sensor signals. Thus the possibilities for sensing relevant parameters in any production process or plant will increase significantly, giving also an improved insight into and an understanding of complex production processes. Because today's processes in, e.g., chemical or steel industry are often highly complex, not fully understood and even less controllable, any improvement in sensing is a fundamental prerequisite to the vision of future production systems.

Mobile communications is a prominent example of the above described advancement and mutual relationship of semiconductor technology and information theory. While this technology has fast and radically changed our personal and professional life, its current impact on the industrial world is by far less. Main reasons for that are the largely differing requirements on mobile communication systems for industrial use, the lack of world-wide accepted standards, and the – up to now – much smaller market. However, the need for cost-effective, reliable, low-latency, but yet flexible communication networks for industrial environments is growing, and is also fueled by the described new types of sensors. While in the past classical cellular communications (GSM, UMTS, HSDPA, LTE) research was clearly separated from research in wireless sensor networks (WSNs), the currently starting research about so-called 5G mobile communication systems clearly envisions systems which allow for the combination of communication between persons (e.g. mobile phones) and communication between machines ("machine-to-machine" [M2M] communications) [1].

Approach

In the area of microsensors and microsystems there is a need for robust and reliable sensors for the monitoring of media utilized in fabrication processes. These may be auxiliary fluids like lubricants or substances associated with the product themselves, e.g., constituents of produced food or chemical products. Interestingly, physical properties of substances can also be used to determine chemical, biochemical, or medical parameters. In standard chemical sensors, very often the chemical sensing process is targeting at a chemical property of a liquid such as the pH-value or the presence of certain compounds within the liquid (e.g., as a result of oxidation processes). A dedicated chemical sensor would employ a chemical interface which selectively reacts with (or adsorbs) the targeted substance and changes its physical properties (e.g., its mass due to adsorbtion). The latter change can be detected by means of suited physical sensors. Particular for industrial applications it appears feasible to, instead of applying a chemical interface where a reaction should take place, employ physical effects or phenomena for the retrieval of chemical information in a liquid. For such applications one adopts the concept of "physical chemosensors", where a purely physical sensor is used to obtain information on the state of the liquid. This approach has the advantage that the design, realization and maintenance of the complex chemical interface can be omitted, yielding a simpler and more cost-effective sensor system. If, for instance, the monitored process is well understood, physical quantities can be used to indirectly determine the chemical state of the liquid. A simple example for this approach is the determination of the alcohol content of a brew by means of a density measurement (before and after fermentation). Alternatively, for more complex processes, physical sensor arrays can be employed, which are related to the sought chemical parameters by means of establishing suitable correlations. Physical chemosensors are suitable for many condition monitoring applications where reliability is an issue [2].

In the area of instrumentation, measurement and sensors we see a growing demand for measurement principles which are contactless and non-destructive, such that production processes can be accurately monitored but without disturbance to the process itself. Main principles to be applied here are the usage of ultrasound and optics, especially laser-based stand-off measurement systems, as well as micro- and millimeter wave sensing. A common principle to all these techniques is the emission of a wave which propagates through a medium which alters the traveling wave. After reception of the wave the changes compared to the transmitted wave are analyzed and from that certain parameters from the medium can be calculated. Main differences between ultrasound, optics and micro- and millimeter waves are reflection, penetration, and transmission properties for different materials from which a large variety of measurement systems arise. Again the current and future improvements in microelectronics and signal processing will continuously expand the performance and cost-effectiveness of sensor systems and enable the measurement of process parameters which are inaccessible today. Millimeter wave sensing may be mentioned as one example which, due to the recent availability of microelectronic circuits, emerges as reliable and yet cost-effective alternative to laser-based systems especially in environments polluted by dust or vapor. A further important area closely linked to millimeter wave sensors is the accurate localization of goods and persons in indoor- and outdoor environments, which is also a necessity for any highly automated production process.

The application of wireless sensor networks to industrial plants and processes is still in its infancy. It will require a major research effort to make WSNs suitable for critical functionality like fast (sample times below 1 ms) online monitoring and control (closing the control loop wirelessly). The largely differing requirements on WSNs for industrial use ask for research at all levels from circuit design for transceivers via protocols for various purposes like, e.g., multiple access or routing, up to cognitive systems which are able to monitor the radio environment (e.g. interference from other mobile communication systems) and adapt its radio parameters accordingly to ensure optimum operation.
Advances in electronics and signal processing serve as basis for accessing and extracting the information from the signals delivered by the envisioned new and/or improved sensors. Besides the application of classical signal processing methods new research foci will be put on the processing of massive data resulting from a very large number of sensors, virtual sensors, and machine learning techniques.

Impact

Modern industrial plants will feature a high level of automation which demands for a solid technological base for control and monitoring systems. The activities in this area lay the f**oundations in terms of technologies** for sensing and signal processing, mainly on the machine level, as well as circuits for communications and sensor control and readout, algorithms, and communication protocols. **Scientific impact** will be created by new methods, principles, algorithms, circuits etc., all at the technological frontier, in the above described fields of signal processing, microelectronics, sensors, and instrumentation. A rich set of methods and technologies is already available in sensing, communications and circuits, but in harsh industrial environments still many sensing problems are unsolved and wireless communications cannot be applied to critical communication paths in industrial plants. This is why a special focus needs to be put on **interdisciplinary research** approaches which bring together technologies and methods from different disciplines and applications. Special scientific impact is expected from the integration of hybrid systems, combining silicon-based electronics with optical, chemical and biological systems, the possibility to build systems operating at millimeter wave frequencies, the possibility to perform distributed signal processing at a large number of low-cost and low-power sensor nodes, and the adaptation of advanced communication technologies, well known in cellular communications, towards the very much different field of industrial communications.

These technological advances will have **industrial impact** by strengthening the production industry due to new and/or improved production process, by, e.g., improving product quality or reducing the use of natural resources. Also companies and industry branches which provide advanced sensing and communications solutions for future industrial plants will be able to grow and expand their business. This directly also transforms into **societal impact** resulting from a strong European industry which contributes to citizen welfare, from an optimized use of resources, from environment protection, and many more.

References

[1] F. Boccardi, et.al: “Five Disruptive Technology Directions for 5G”, IEEE Communications Magazine, Vol. 52, No. 2, pp. 74 – 80, Feb. 2014.

[2] B. Jakoby and M.J. Vellekoop: “Physical sensors for liquid properties”, IEEE Sensors Journal, Vol. 11, No. 12, pp. 3076-3085, 2011.

[3] J. Atzlesberger, R. Cihal, M. Brummayer, P. Reisinger and B. Zagar: “Sub-surface defect detection in steel sheet”, in Measurement Science and Technology, Vol. 24, No 8, IOP, pp. 084003, 2013.

[4] D. Hofer and B. Zagar: “A numerical approximation of the Huygens-Fresnel Integral - Simulations on a rough wetting problem”, in Measurement, Vol. 46, No 8, pp. 2828-2836, 2013.

Keywords

Signal Processing, Integrated Circuits, Microsensors, Sensor Networks, Wireless Systems, MEMS and Microsystems

Competencies

Research competence in sensors, signal processing and microelectronics is represented by the following institutes and their associated labs:

- **Institute of Microelectronics and Microsensors** with research focused on microsensors and microsystems for monitoring of fluids and their physical parameters and lab facilities including a clean room and electronics laboratories for the (prototype) fabrication and characterization of sensors and microsystems,
- **Institute of Measurement Technology** with research focused on ultrasound- and laser-based measurement systems, digital signal- and image processing, optical tomography, and measurement electronics,
- **Institute of Communications Engineering and RF-Systems** with research focused on radio frequency integrated circuits for radar applications, radar system design, MIMO radar, industrial radar sensors, radar-based local positioning systems and sensor fusion, wireless sensor networks for industrial applications, architectures and signal processing methods for wireless transceivers and lab facilities including micro- and millimeter wave measurement equipment up to 170 GHz, antenna measurement chamber, and software radio prototyping equipment,
- **Institute of Integrated Circuits** with research focused on the design (including EMC and ESD issues) and design-for-test of integrated circuits in the area of analog, digital, and mixed analog digital circuits used in e.g. high precision data converters, other baseband applications like operational amplifier and filter design as well as RF circuits including lab facilities to characterize integrated circuits,
- **Institute of Signal Processing** with research focused on algorithmic-, architectural- and hardware-oriented aspects of signal processing systems in the area of information and communication systems, radio frequency and baseband integrated circuits, battery- and power management units for mobile devices as well as automotive applications and lab facilities for prototyping on embedded systems
- **Institute of Bioinformatics** with research focused on (bio-) signal processing and normalization/summarization of high-dimensional and noisy measurement data like micorarray gene expression measurements or DNA/RNA sequencing. In particular the Institute of Bioinformatics applies machine learning and statistical techniques like deep learning and latent variable models to massive data sets to remove measurement noise, to extract clean signals, and to detect in the data rare but relevant events with a low false discovery rate. All institutes contribute to basic and applied research, with funds granted from competitive funding programs at national (FWF, FFG, COMET program, etc.) and EU level.

Proponents

Univ.-Prof. Dr. Sepp Hochreiter
Institute of Bioinformatics

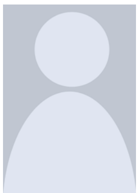
sepp.hochreiter@jku.at
http://www.bioinf.jku.at/

Univ.-Prof. Dr. Mario Huemer
Institute of Signal Processing

mario.huemer@jku.at
http://www.jku.at/isp

Univ.-Prof. DI Dr. Bernhard Jakoby
Institute of Microelectronics
and Microsensors

bernhard.jakoby@jku.at
http://www.ime.jku.at/



A.Univ.-Prof. DI Dr. Tim Ostermann
Institute of Integrated Circuits

timm.ostermann@jku.at
http://www.riic.at/

Univ.-Prof. DI Dr. Andreas Springer
Institute of Communications Engineering and
RF-Systems

a.springer@nthfs.jku.at
http://www.nthfs.jku.at/

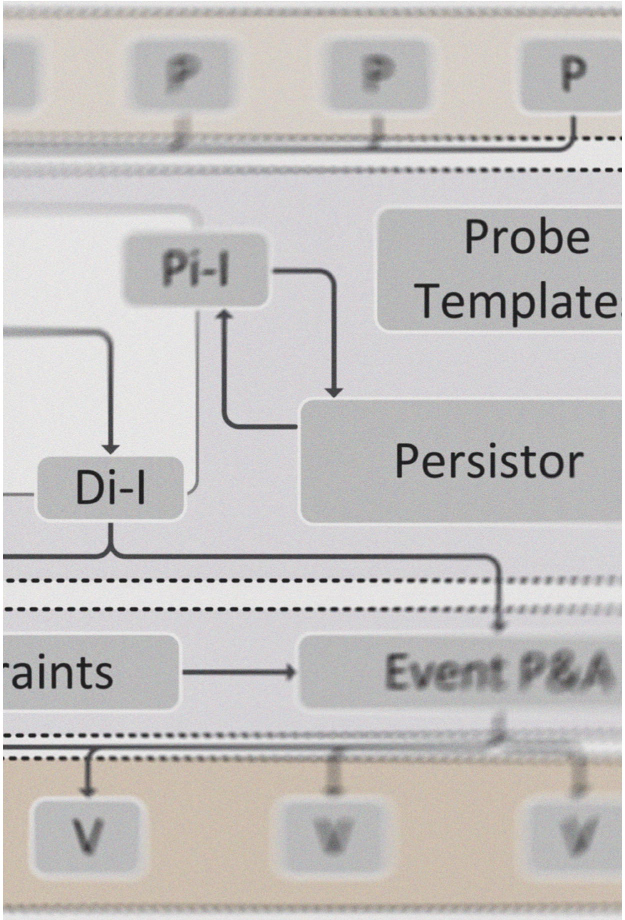
Univ.-Prof. DI Dr. Andreas Stelzer
Institute of Communications Engineering
and RF-Systems

andreas.stelzer@jku.at
http://www.nthfs.jku.at/

Univ.-Prof. DI Dr. Bernhard Zagar
Institute of Measurement Technology

bernhard.zagar@jku.at
http://www.jku.at/emt

Next Generation Software Technologies: Smart Engineering for Systems of Systems



"The next generation software technologies are expected to strongly improve the efficiency of software system development processes and with it the quality of software systems and systems of systems."

Alexander Egyed

Focus Line 3:

Future and Emerging Enabling Technologies for Production Systems

Coordinator:

Univ.-Prof. DI Dr. Alexander Egyed M.Sc.
Institute of Software Systems Engineering

alexander.egyed@jku.at
http://www.jku.at/isse

Research Focus

- Collaborative Software Systems Engineering to Support Diverse Engineers, Teams and Technologies
- Effective Monitoring and Analysis of Software Systems to Gauge Correct Behavior
- Maximal Reuse of Engineering Assets Including Software, Tests, Documentation, Models, and Mechatronic Artifacts
- Sustainable Engineering Coping with Change and Evolution
- Models, Methods and Tools for Quality Control

Motivation

An increasing number of software systems today are systems of systems (SoS) with decentralized control; support for multiple platforms; inherently conflicting requirements; continuous evolution and deployment; as well as heterogeneous, inconsistent, and changing elements. Such systems are often developed and evolved by heterogeneous and globally distributed teams and communities. SoS are typically based on system-of-systems architectures spanning multiple heterogeneous systems. Industrial SoS evolve over many years and need to be continuously adapted to meet customer, market and technology requirements. Terms used in literature to describe SoS include ultra-large-scale systems (Northrop 2006) or software ecosystems (Bosch 2012). SoS comprise multiple heterogeneous systems that are managed independently while interdependencies still need to be managed. For instance, even if the different systems in a SoS can exist independently, they use shared resources to meet the overall system requirements. SoS thus rely on the large-scale integration of independent and self-contained systems to satisfy a global need. SoS are characterized by the heterogeneity of platforms and networks they operate on; the diversity of stakeholders with changing and ephemeral needs; and the dynamicity of their operating environment.

Vision

The development and evolution of SoS has been compared to the "development of cities" while conventional software engineering methods rather support "building a house". SoS can no longer be planned, engineered, and evolved in a top-down fashion (Northrop et al. 2006). Novel technologies, methods and tools are needed that address SoS characteristics:

Operational and managerial independence of the elements. The systems an SoS comprises are self-contained and useful independently. They are engineered, operated, and managed individually and they maintain their existence independent of the SoS. Understanding the requirements of SoS is challenging as these systems will be developed and used by diverse stakeholders with unavoidably conflicting and changing needs. SoS frequently are ecosystems (Bosch 2012) with heterogeneous users and user communities driving their evolution.

Emerging behaviour. The behaviour of a SoS cannot be predicted but rather emerges from the combination of the behaviours of the systems it comprises. The principal purposes of the SoS are fulfilled by these behaviours. Advanced features for monitoring the elements of a SoS and diagnosing errors are promising including methods for incorporating the feedback about actual behaviour to the overall SoS.

Decentralized and heterogeneous component systems. The scale of SoS means that they will necessarily be engineered, operated, and evolved in a decentralized manner. A SoS will not be constructed from uniform parts but will be integrated from heterogeneous, inconsistent, and changing elements. There will typically be some misfits, especially if the systems are extended or repaired during evolution.

Evolutionary development. A SoS is not created fully formed but comes into existence gradually. Often SoS are developed in stages and by different types of developers. For example, a core platform of a SoS might be developed by experts while adopters build extensions and create specific solutions based on the platform to meet the needs of a market segment. There is also an increasing need to integrate new capabilities into a SoS while it is operating. New and different capabilities will be deployed, and unused capabilities will be dropped; the system will be evolving not in phases, but continuously and incrementally. For instance, it is common to evolve only individual systems instead of the entire SoS. These characteristics are not independent and imply a change in the fundamental assumptions that underlie today's software engineering approaches (Boehm 2006).

Approach

New software engineering approaches are necessary to support the development of SoS that go beyond the development of individual software systems. These are discussed next:

Technologies for Multi-Team Engineering
The engineering of a large SoS is an inherently collaborative process that involves diverse engineering teams and heterogeneous engineering tools. While these multi-disciplinary engineering teams have to collaborate continuously, their tools are nearly always independent, single-user applications. The difficulty of keeping the artifacts created with these tools in sync is a well-known problem. Yet, no adequate solutions exist. Technologies for Multi-Team Engineering would focus on a novel engineering infrastructure for storing engineering artifacts, navigating, and reusing them. We envision automated support for capturing traceability, supporting distributed collaboration, handling consistency checking or transformation across an entire project, and supporting the evolution of arbitrary engineering artifacts and their meta-models.

Monitoring and analysis of Systems of Systems. Monitoring and analyzing the performance of SoS is challenging because a single operation can cross the boundaries of programming languages, virtual machines, operating systems and servers. Service orientation, cloud computing and load-balanced server farms even add to the problems. SoS are often so complex that it is impossible for single stakeholders to know all the components and features in detail. We therefore envision the automatic extraction of uniform high-level views from low-level components to understand the emerging behaviour of SoS. Such views can, for example, be generated from probes that are injected into critical components or interfaces. Constraints will be specified to monitor whether the observed values are within plausible ranges and measures can be taken immediately if in invariant is invalidated. Since SoS mostly work under real-time conditions it is not possible to evaluate the monitored data on the fly. We therefore plan to develop tracing techniques that allow the efficient capturing of events and data and an offline replay of the system behaviour for anomaly detection, behaviour analysis and model-based testing of SoS.

Technologies for Design, Reuse, and Evolution Support. Evolution is the rule and not the exception in practice due to ever changing requirements, technologies, and markets. Many industrial SoS have a lifetime of 10ß30 years and are facing continuous evolution due to changing software technology, new customer requirements, and new market situations. Software systems face "aging", i.e., they degrade and erode over time due to changes up to a point where their key properties no longer hold. These challenges are specifically relevant in the context of SoS which comprise multiple, heterogeneous software systems that are managed and evolved independently, typically in many variants and versions. Existing software engineering methods and tools give only partial answers to the design, reuse and evolution of SoS. For instance, in SoS customers or external partners often even evolve the systems themselves, e.g., when developing specific extensions. Novel methods are needed to ease upgrading a system or parts of it at reasonable costs if the original system and the deployed system have evolved independently since the original deployment. At the same time users demand flexible systems that can be adapted rapidly and reliably to meet changing requirements, to increase performance, or to update technology. Approaches are needed for designing flexible and evolvable systems that can be composed rapidly and at low cost based on reusable components. In many environments, systems even need to evolve at runtime to ensure their continuous operation. We thus plan to enhance methods for requirements engineering, software architecture, and product lines to better address the characteristics of SoS.

Quality Control for Systems of Systems Development
We envision concepts, models, methods and tools for specifying, extracting and measuring quality related information at both the level of individual systems and system of systems to support quality assessment and quality control processes. This includes the extraction of such information from artifacts and system management data and comprises methods like static code and design analysis, architecture analysis and reviews. Quality control for systems of systems needs to employ techniques of multi-team engineering for achieving and supporting cross-system quality control analyses and processes. The resulting quality models can be integrated with quality data from systems of system monitoring. In addition, current approaches miss a holistic quality view on system components (mechatronic and cyberphysical objects) including mechanical, electrical, pneumatical and software perspectives. Thus we need an integrated model, not only combining different abstraction levels (component, system, systems of systems) for analysing mechatronic systems, but also integrating different mechatronic and cyberphysical perspectives (e.g., mechanical, electrical and software). On a process level, support for cross-system (multi-team) quality analysis and control is required.

Sustainable Systems of Systems
For developing mechatronic systems documentation of design decisions for the various perspectives (e.g. mechanical, electrical and software) is essential. We envision a documentation approach based on knowledge management for supporting decision documentation in a system-of-systems context, including methods and tools for efficiently capturing, maintaining, sharing and reusing decisions and decision rationales. Such an approach requires tracing of design decisions to arbitrary artifacts and models, concepts from multi-team engineering for keeping models consistent, and concepts supporting independent evolution.

Research Methods
As research methods we plan on using a combination of constructive and empirical methods with a strong focus on applied research. We plan to use PLM-based domain analysis, prototyping, and the development of models, languages, tool environments, technologies and infrastructures. Validation with industrial partners is performed using methods like design science and action research. Other validation methods used are case studies, surveys and experiments with industrial experts.

Impact

The next generation software technologies are expected to strongly improve the efficiency of software system development processes and with it the quality of software systems and systems of systems. Key impacts are increased collaboration and awareness of engineering teams, increased efficiency and effectiveness of engineering processes, better maintainability through improved visibility and traceability, long-term sustainability and evolvability of systems, and increased reusability of engineering artifacts.

An improved system of systems quality has a range of downstream benefits for industry, commerce, society and the scientific community. These indirect impacts are the expected downstream effects of better software engineering:

Industrial and Commercial Opportunities
The industrial and commercial opportunities of smart engineering for companies specialized in industrial engineering are far better predictability and considerably lower engineering costs. Further, companies will be enabled to face the ever increasing challenges of nowadays mechatronic systems like high reliability, security and sustainability.

Impact on Society
The envisioned work would not only help to significantly increase central aspects of mechatronic and cyberphysical systems, but is essential for their functioning. Important aspects to be addressed are reliability, security and sustainability of such systems. As the targeted mechatronic systems (power plants, trains, etc.) are vital and indispensable for society, their proper functioning and high reliability is a major concern of our society.

Scientific Impact
The envisioned work would be ground breaking from a scientific point of view. Naturally, this work would lead to numerous papers in high-profile, peer-reviewed publications as well as talks in con-

ferences and workshops. This would improve the visibility of JKU/ Upper Austria in the scientific community and attract international scholars. This work would also benefit multi-disciplinary research as it integrates mechatronical engineering (from mechanical engineering, electrical engineering, control engineering) and software engineering. In turn, this creates synergies that further benefit our impact in the community.

References

[1] B.W. Boehm and J. A. Lane: "21st century processes for acquiring 21st century software-intensive systems of systems", Crosstalk: Journal of Defense Software Engineering, Vol. 19, No. 5, pp. 4–9, 2006.

[2] Jan Bosch: "Software ecosystems: Taking software development beyond the boundaries of the organization", Journal of Systems and Software, Vol. 85, No. 7, pp. 1453-1454, 2012.

[3] A. Egyed: "Automatically Detecting and Tracking Inconsistencies in Software Design Models", IEEE Transactions on Software Engineering (TSE), Vol. 37, No. 2, pp. 188-204, March/April 2011.

[4] A. Egyed and D.S. Wile: "Support for Managing Design-Time Decisions", IEEE Transactions on Software Engineering (TSE), Vol. 32, No. 5, pp. 299-314, May 2006.

[5] A. Egyed and R. Balzer: "Integrating COTS Software into Systems through Instrumentation and Reasoning", International Journal of Automated Software Engineering (JASE), Vol. 13, No. 1, pp. 41-64, 2006.

[6] A. Egyed and P. Grünbacher: "Identifying Requirements Conflicts and Cooperation: How Quality Attributes and Automated Traceability Can Help," IEEE Software, Vol. 21, No. 6, pp. 50-58, November/December 2004.

[7] A. Egyed: "A Scenario-Driven Approach to Trace Dependency Analysis," IEEE Transactions on Software Engineering (TSE), Vol. 29, No. 2, pp. 116-132, February 2003.

Competencies

The JKU ranks Top 50 among the software engineering research institutions in the world according to Microsoft Academic Search. The JKU Software Engineering Master's Study was ranked the best CS program in Austria and the best technical program at the Johannes Kepler University. The JKU Business Informatics Study is the only international accredited study program at the JKU and has been highly ranked among studies in Austria, Germany, and Switzerland. The JKU thus has broad recognitions in both science and teaching in software engineering worldwide.

The **Institute of Software Systems Engineering** (ISSE), the **Institute of System Software** (SSW) and the **Institute of Business Informatics - Software Engineering** (WIN-SE) are part of JKU and leading research institutes on software and systems engineering. The work of the institutes cover a wide area of software engineering, from requirements capture, software and systems architecture and design, testing, to maintenance; including software modeling (consistency, traceability, impact of change), product line engineering (and other forms of variability), requirements engineering, monitoring, software quality, software processes, domain-specific languages, static and dynamic program analysis as well as compilation technology.

The institutes collectively employ around 60 researchers, which are supported with grants from Austria, Canada, European Union, and USA – covering both academia and industry. Funding comes from national research grants like the Austrian Science Fund (**FWF**) and the Austrian Research Promotion Agency (**FFG**) and from applied research grants from companies such as **IBM**, **Oracle**, **Siemens**, and **Trumpf** or the **SCCH** and the **ACCM** (which are company-funded consortia). The institutes also hosted prestigious **Christian Doppler Laboratories** (CDL) like the CDL on Software Engineering (WIN-SE, 1992-1999) and the CDL on Automated Software Engineering (SSW, 2005-2012).

Currently the ISSE hosts the **CDL on Monitoring and Evolution of Very-Large-Scale Software Systems** (2013-2020). This lab works on theoretical foundations as well as methods, tools, and infrastructures for managing and supporting the monitoring and evolution of very-large-scale software systems. The lab collaborates with the **Institute of System Software** (SSW) as scientific partner and three industrial partners: **Siemens VAI Metals Technologies GmbH** is the world's leading engineering company for metallurgical plants. **KEBA AG** provides advanced software solutions for industrial, banking, and service automation. **Compuware Austria GmbH** is a technology leader in the area of application performance management. For details see: http://www.isse.jku.at/, http://www.ssw.jku.at, http://www.se.jku.at

Proponents

Univ.-Prof. DI Dr. Alexander Egyed M.Sc.
Institute of Software Systems Engineering

alexander.egyed@jku.at
http://www.jku.at/isse

A.Univ.-Prof. Mag. Dr. Paul Grünbacher
Institute of Software Systems Engineering

paul.gruenbacher@jku.at
http://www.jku.at/isse

O.Univ.-Prof. DI Dr. Dr.h.c.
Hanspeter Mössenböck
Institute of System Software

hanspeter.moessenboeck@jku.at
http://ssw.jku.at/

A.Univ.-Prof. Mag. Dr. Reinhold Plösch
Department of Business Informatics - Software Engineering

reinhold.ploesch@jku.at
http://www.se.jku.at/

O.Univ.-Prof. DI Dr. Gustav Pomberger
Department of Business Informatics - Software Engineering

gustav.pomberger@jku.at
http://www.se.jku.at

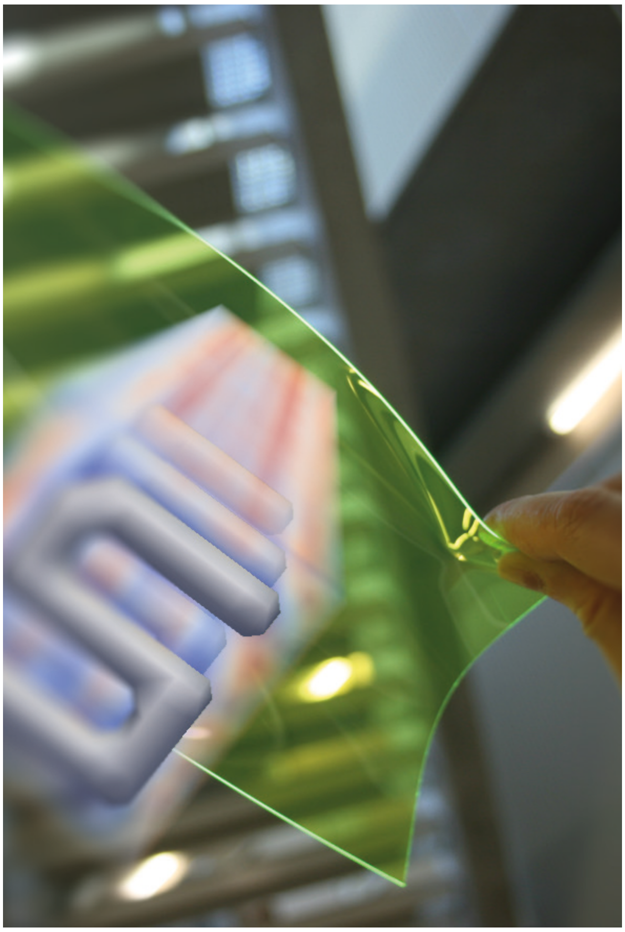
Ass.-Prof. Dr. DI Rainer Weinreich
Department of Business Informatics - Software Engineering

rainer.weinreich@jku.at
http://www.se.jku.at

Keywords

Systems of Systems, Multi-Team Engineering, Autonomous and Interoperable Network-Based Systems, Monitoring and Analysis of Systems of Systems, Evolution and Variability, Knowledge Management, Tool Infrastructures.

Machine Perception as Supporting Technologies



"Machine perception is a technology of central importance to a large number of automatized processes in the producing industry today, and this role will continue to become more and more important"

Gerhard Widmer

Focus Line 3:

Future and Emerging Enabling Technologies for Production Systems

Contact:

Univ.-Prof. DI Dr. Gerhard Widmer
Institute of Computational Perception

gerhard.widmer@jku.at
http://www.cp.jku.at/

Research Focus

- Sensor Technology
- Signal Processing and Analysis
- Pattern Recognition, Classification, Prediction
- Machine Learning and Probabilistic Data/Process Modeling

Vision

Machine perception, interpreted in the broadest sense as the **process of analyzing**, **interpreting**, and ultimately ‚**understanding**‘ low-level **sensory input** in a machine, is a technology of central importance to a large number of automatized processes in the producing industry today, and this role will continue to become more and more important -- from application fields such as manufacturing (e.g. quality control, process monitoring) to robotics. Our vision is to help making machine perception a standard tool in industry and production, a tool that is competently used by well-trained computational engineering specialists.

Signal processing is the key enabler technology for machine perception and the essential link from software to hardware. Leading-edge research on algorithms for **sensor integration** as well as efficient signal processing techniques to handle the massive amount of sensory input data have to be employed. The latter is extremely important in order to meet today‘s **low-power requirements** in battery driven environments such as mobile and wearable devices.

Another example for machine perception is computer vision – i.e., machine perception from digital images. Digital images play an important role in our professional and personal life. They represent the fundamental basis for **imaging** and **display technologies**, as well as for **image processing and visualization**. The future of digital images may lie in an entirely new way of recording and reconstructing light, called **light fields**. Compared to two-dimensional images, light fields are four-dimensional and sample ray information rather than pixels. In future, light fields have the potential to radically change everything we related to 2D images today – including **computer vision**.

Approach

The fundamental technologies and research fields underlying computer perception are machine learning, pattern classification and recognition, statistical and probabilistic data modeling, signal processing and analysis, sensor technology. Our specific approach to bringing these technologies to bear for the benefit of technology stakeholders is threefold:

All the above-mentioned technologies are part of our teaching portfolio at the JKU, especially at master student and PhD level, mainly as part of the **Computer Science** main subjects **Pervasive Computing** and **Computational Engineering**. By training gifted students in the context of practical project and theses, we aim at producing highly competent graduates with both an understanding of formal and mathematical mehotds, and practical experience in building systems that solve hard problems.

Fundamental Research: We continually improve our set of methods and develop new technolgies for solving complex recognition and process tracking problems, mainly in the areas of audio perception, image processing, biometric recognition, computer vision, light-field processing, and optics and sensor technology.

Research: We seek direct interaction with local and international industrial and scientific partners, in the context of masters and PhD thesis and national or international funded projects. Through our involvement in initiatives such as the Computational Engineering Colloquium [1], for instance, we also try to establish direct connections between excellent students and interested industrial stakeholders in the local area. Joint projects together with top-level research cooperations and universities worldwide, such as **Microsoft Research** or **Harvard University**, underline the scientific quality of our work in the context of machine perception.

Impact

Machine perception and the underlying technologies of **machine learning** and **pattern recognition** permit the automatisation and optimization of a wide variety of commercial and industrial production processes, supporting tasks such as automatic quality control, process monitoring, interaction and control of complex processes, etc.

In the more specialized domain of the **Institute of Computational Perception’s** (ICP) active scientific research (audio, music perception), the impact – in addition to the high international reputation and position of excellence of the research group in the world of Sound and Music Computing -- is materializing in real-world applications and devices that change the way digital music is consumed, experienced, and its use is monitored internationally. For instance, cooperations with the Danish audio company **Bang & Olufsen** have resulted in the world‘s first digital media player with on-board musical intelligence [2]; contributions to the ongoing EU project PHENICX are changing the way music concerts are presented to music lovers via iPad apps and media streaming [3]; and ongoing work on audio stream segmentation and audio identification will be used to automatically monitor and evaluate digital broadcast and streaming media.

From a sensor technology point of view the current light-field related research by the **Institute of Computer Graphics** (ICG) leads to new applications in human-computer interfaces, photography, image and video processing, microscopy and endoscopy, as well as in real-time visualization of large data sets. One recent example is the development of the world’s first transparent, flexible and disposable image sensor, that was introduced in cooperation with Microsoft [4]. The impact of light-field technology in general, however, include also **3D displays** and **3DTV**.

Competencies

The competencies of the JKU computer science department in the context of machine perception include: audio analysis, pattern recognition, image processing, machine learning, probabilistic models, statistical and adaptive signal processing, signal processing architectures and implementations, visual computing, imaging technology, image reconstruction, sensor technologies, and optics, computer vision, visualization, and computer graphics.

References

[1] Computational Engineering Colloquium. Available: http://ce.informatik.jku.at/colloquium.

[2] Beosound 5. Available: http://www.bang-olufsen.com/en/sound/sound-systems/beosound-5

[3] RCO Editions. Available: http://www.concertgebouworkest.nl/en/rco-editions

[4] A. Koppelhuber and O. Bimber: "Towards a transparent, flexible, scalable and disposable image sensor using thin-film luminescent concentrators", Optics Express, Vol. 21, No. 4, pp. 4796-4810, 2013. Available: http://www.opticsinfobase.org/oe/abstract.cfm?uri=oe-21-4-4796.

[5] press: http://www.jku.at/cg/content/e151291

Proponents

Univ.-Prof. DI Dr. Gerhard Widmer
Institute of Computational Perception

gerhard.widmer@jku.at
http://www.cp.jku.at/

Univ.-Prof. Dr. Mario Huemer
Institute of Signal Processing

mario.huemer@jku.at
http://www.jku.at/isp

Univ.-Prof. Dr. Oliver Bimber
Institute of Computer Graphics

oliver.bimber@jku.at
http://www.jku.at/cg

Keywords

Machine Learning, Signal Processing, Signal Analysis, Sensor Technology, Computer Vision, Image Processing, Audio Analysis, Pattern Recognition

Focus Line 4: Mastering Complexity in Production and Communication Systems

FL4-01 **Computational Planning, Optimization, Logistics and Supply Networks**
Coordinator: Karl F. Dörner - Institute of Production and Logistics Management

FL4-02 **Safety, Risk and Uncertainty Management**
Coordinator: Dmitry Efrosinin - Institute of Stochastics

FL4-03 **Cyber-Physical Products**
Coordinator: Alois Ferscha - Institute of Pervasive Computing

FL4-04 **Man-Machine Symbiosis**
Coordinator: Alois Ferscha - Institute of Pervasive Computing

FL4-05 **Visual Data Analytics**
Coordinators: Marc Streit - Institut of Computer Graphics, Josef Küng - Institute of Application Oriented Knowledge

FL4-06 **Computational Mathematics in Industrial Applications**
Coordinators: Bert Jüttler Institute of Applied Geometry, Erich Peter Klement - Department of Knowledge-Based Mathematical Systems

FL4-07 **Mathematical Simulation and Financial Mathematics**
Coordinator: Gerhard Larcher - Institute of Financial Mathematics

Computational Planning, Optimization, Logistics and Supply Networks

"New smart and collaborative optimization techniques on all the different planning hierarchies on operational as well as on tactical level can provide a better usage of production resources and improve the matching of supply with demands."

Karl Dörner

Focus Line 4:

Mastering Complexity in Production and Communication Systems

Coordinator:

Univ.-Prof. Mag. Dr. Karl Dörner
Institute of Production and Logistics Management

karl.doerner@jku.at
http://www.jku.at/plm/content

Research Focus

- Decisions in Logistics and Supply Chain Management
- Collection, Management and Analysis of the (Massive) Amount of Data Entailed by Frequently Occurring Large-Scale Problems
- Incomplete Information Consideration of Non-Rational Human Behavior
- Integrated Optimization Models Where Several Intertwined Subproblems are Considered Simultaneously

Vision

When seeking to make appropriate **decisions in logistics and supply chain management** (SCM), operators face a major challenge, in that the **procurement**, **production**, and **distribution processes** consist of strongly interrelated tactical and operational subproblems (e.g., in manufacturing, lot-sizing decisions directly influence scheduling; the resulting production plan determines procurement and distribution processes). These subproblems in turn are governed by several autonomous departments or cross-linked companies, and thus exposed to separate decisions made by vendors, service providers, and buyers. Intertwined complex subproblems in logistics and SCM with rich and real-world constraints are very difficult to handle. These complex problems are very hard to model and even harder to solve. Hence modeling support is required, but especially the formalization of mathematical models is not easy. Several real-world conditions (e.g., the occurrence of multiple-objectives, data uncertainties and dynamics) complicate the situation and induce a computational intensive solution process due to a huge number of decision variables and constraints. Moreover highly efficient solution approaches that can deal with these conditions need to be developed. The development of models and methods for intertwined. subproblems is very challenging, even when only one actor in the SC is considered. However, a large number of decision makers with competing objectives are involved in SC networks. Their behavior and relation to each other need to be modeled and analyzed too.

New technologies and developments enable the **collection of data in real time**. Further difficulties arise with the **collection**, **management and analysis of the (massive) amount of data** that is **entailed by frequently occurring large-scale problems**. The information must be collected, analyzed and can be reused in the optimization process. The fact that some input data often is uncertain or dynamic in the sense that the information appears during the operation without any prior information is an additional complicating factor. With increasing data volume, the inaccuracies and approximation necessities rise. In turn, the presence of **private** or **incomplete information** necessitate the **consideration of non-rational human behavior**. All these actualities impede the expedient use of largely available and steadily advancing optimization methods.

Currently, the only way to handle rich, real-world SC problems on a tactical and operational level is to **split the overall problem into subproblems** and to **solve them individually**. This is insufficient to resolve integrated SC decisions. Current economic developments that induce an increase of the interdependencies between companies, volatility, and uncertainty make the problem even more acute.The requirements to handle complexity in production and logistics appear on several levels at the supply chain. The availability of new data sources (e.g. current status of the machines, location and stock level of the raw material, expected arrival time of raw material,…). The availability of dynamic real-time data (e.g. current degree of capacity utilization) enables the possibilities for new planning concepts:

On the lotsizing level: In some branches customer require more specialized and individual products (e.g. individual assembly of cars or furniture). These aspect results in a larger variety of goods and in smaller lot-sizes. The procurement process becomes more challenging, the scheduling and lot-sizing decisions in the production process are more complex. Sequence dependency and availability of raw material has to be considered. The availability of real-time production data makes it possible to handle the new complex scheduling problem. Although new algorithms and planning concepts are required. In addition through the availability of current production data immediate calculations of delivery dates and prices are computable. New (emergency) orders can be easily integrated in the current production plan. The dynamic adaptation of the production plans require also new concepts in inventory management. In complex supply networks risk pooling concepts and strategies for avoiding stockouts are inevitable.

On the production plant level: The complete production process can be reoptimized by combining reality with computer simulation. Reactive simulation-optimization processes provide accurate planning of the current production program. Real-time data can be exchanged with the simulation model. Reality as well as simulation models can learn from each other. The integration of real-time information requires adapted concepts in simulation-optimization.

On the distributed manufacturing level: Large companies produce in different production plants. For different production plants complete information is not available. Especially when this production plants are owned by different owners. Different coordination mechanisms can be considered. A fully centralized planning approach, in which a central institution receives all production orders and determines an optimal allocation for the entire system. This approach requires that all manufacturers reveal complete information not only on their production orders, but also about their internal cost structure, capacities, and perhaps other production orders to the centralized planning institution. Decision maker of different manufacturing plants might not be willing to provide that information, or can have incentives to distort some of it to manipulate the resulting allocation in their favor. As an alternative, we can therefore consider a centralized auction mechanism, which requires decision makers only to provide information on the production orders to be reallocated and to make bids on those orders. A decentralized auction model, in which decision makers run auctions on production orders they intend to pass on to other carriers. Here the amount of information which carrier have to provide is further reduces, although the allocation will be less efficient. Decision maker can also perform a bilateral exchange on dedicated orders.

On the supply network level: For producing production orders raw materials and assembly parts are required. The different materials have to be available at the different production plants. Modified sourcing concepts are required when the assignment of production orders will often change. The contracts with the supplier have to be modified. Contracts are required which make more flexible sourcing concepts possible.

New smart and collaborative optimization techniques on all the different planning hierarchies on operational as well as on tactical level can provide a better usage of production resources and improve the matching of supply with demands.

Approach

The first step towards integrative problem solving of complex problems in production and logistics is a (semi-) automated modelling approach. The development of **integrated optimization models where several intertwined subproblems are considered simultaneously** is a very difficult, but very important task. Focusing on just one single subproblem without taking into account the interdependencies can lead to suboptimal solutions. Research in this field is very active and models and methods are steadily evolving. However, the existing models and approaches concentrate on the formalization and combination of deterministic problems mostly combining just two subproblems, e.g., combined lotsizing and scheduling problem, inventory routing, or production routing. Combinations of routing problems with different down and upstream operations are presented in a literature survey by Schmid, Doerner and Laporte (2013) [6]. For modeling complex problems we go important steps further and consider several intertwined subproblems in an integrated fashion, considering multiple objectives, stochastic and dynamic problem characteristics. Additionally, we need a generic modeling framework, which will cover the need for automated model generation. Models and methods for multiple tier SC networks: In multiple tier SC networks, human behavior and other unforeseeable, peripheral inuences from SC participants (e.g., autonomous persons, non descriptive social interactions, team-negotiation and -decision processes) influence the decision making process. Hence, the integration of human behavior/competition into SC models will be also important in the future.

The advantages and strength of very promising approaches that have been recently developed for problems in logistics and SCM have to be exploited. As most of them focus on the solution of individual subproblems only, the adaptation and further development of currently state-of- the-art design concepts is necessary to allow an efficient solution of integrated problem formulations that consider the interdependencies of subordinated problems in the future. In addition, the combination of different solution strategies might be beneficial. Solution approaches that have been successfully applied to a large number of optimization problems in the past are for example set covering/set partitioning [1], local search based metaheuristics such as variable neighborhood search (VNS) [4,5]), adaptive large neighborhood search (ALNS) [3], and the hybrid genetic algorithm with advanced diversity control by Vidal et al. Hybrid approaches that combine components from several different optimization techniques.

Recently published and very promising solution methods in the area of **Multi Objective Combinatorial Optimization** (MOCO) are for example the multi-directional local search by Tricoire [7], the two-phase approach by Parragh et al. [4], the adaptations of the branch and cut by Jozefowiez et al., the non-dominated sorting-based multi-objective evolutionary algorithm NSGA-II by Deb. Truly, advanced solution approaches will need to be able to handle uncertain input data to avoid inferior decisions. For an overview of solution techniques related to metaheuristics, refer to [2]. In real-world decision problems, multiple decision criteria and uncertainty are very frequently co-occuring. Many existing approaches solve the problem by using scalarization techniques that eliminate the multi-objective aspect of the problem before the computational analysis, so the stochastic MOCO problem is reduced to a single objective one. Recently published methods that preserve the multi-objective nature of the problem during the computational analysis are surveyed by Gutjahr and Pichler in [2]. In order to solve problem with real world data we need to develop models and approaches for MOCO problems with stochastic problem components. If neither an analytical expression is available nor numerical computation of the operator is possible, sampling techniques (e.g., Monte Carlo simulation or full simulation models) can be used to generate an estimate for the expected value. The combination of sampling approaches and optimization techniques, which is referred to as simulation based optimization has huge potential, since the advantages of both approaches are combined, time-dynamics and stochastic behavior can be explicitly considered, and solutions are generated quickly [5].
Certainly, one of the main aims from the solution technique side is not only to further develop promising solution concepts, but also to **combine methods** from **different research disciplines** and integrate them into a **generic hybrid solution framework**. The **hybridization of metaheuristics** with other optimization techniques is a very active and promising research field. Recently, researchers focused on **hybridizing metaheuristics with complementary (meta)heuristics, constraint programming**, tree search methods, problem relaxation, dynamic programming and even machine learning and **data mining techniques**.

Impact

Summarizing, complex, interdependent SC decision problems with real-time data have not yet been sufficiently solved. The availability of powerful real-time data acquisition means and efficient (hybrid) solution methods for the subproblems have to be developed which can use this real world data. We expect that the integration of real-time data into well known solution concepts will be reused by international research groups in designing hybrid modeling and solution techniques for various application areas. Although various SC types exist, we will focus on the optimization of industrial supply chains. We will model and solve the problems in an integrated fashion. Moreover, we put a strong focus on the integration of real-time (highly dynamic) data, on the development of models for discrete SC optimization problems and on the development of efficient (hybrid) approaches to be able to **tackle multi-objective, stochastic and dynamic optimization problems with rich real world constraints.**

Competencies

The department of production and logistics management consists of 12 researchers on a pre- and post-doc level. The main research topic is the development of **innovative solution techniqes** for **decision support** to solvel **real-world problems** with rich constraints and real world characteristics. The mehods are applicable for strategic and tactical decision problems. The main application areas are transportation and logistics, supply chain services and networks, production logistics.

Karl F. Doerner is professor at the department of production and logistics management since March 2011.Previously he was assistant professor in the department of production and logistics at the University of Vienna. He has notable experience developing solution methods for rich and real-world vehicle routing problems (including problems with stochastic/dynamic characteristics and multi-objective optimization). Recently, he focused on the development of hybrid methods (published in journals such as Transportation Science, Networks, and OR-Spectrum). He has co-authored more than 70 peer-reviewed scientific publications (more than 40 papers in peer-reviewed journals) in the field of transportation logistics. In the Handelsblatt ranking of researchers in business administration in German-speaking countries published in 2012, he was ranked number 37 (achievement in research since 2008) and number 94 (lifetime achievement). He organized the Matheuristics 2010: Third International Workshop on model-based metaheuristics. Prof. Doerner is the head of the CD Laboratory for efficient resource management in intermodal transportation. At the moment, he is also contributing to the project Hybrid- MOOP - Client-centered multi-objective optimization, funded by the FWF, which seeks to investigate hybrid solution techniques for multi-objective problems in the application area of school bus routing and service technician routing.

Proponent

Univ.-Prof. Mag. Dr. Karl Dörner
Institute of Production and
Logistics Management

karl.doerner@jku.at
http://www.jku.at/plm/content

References

[1] C. Archetti, K. F. Doerner and F. Tricoire: "A heuristic algorithm for the free newspaper delivery problem", European Journal of Operational Research, Vol. 230, No. 2, pp. 245-257, 2013.

[2] W. Gutjahr and A. Pichler: "Stochastic multi-objective optimization: a survey on non-scalarizing methods", Annals of Operations Research, to appear, 2014.

[3] A. Kovacs, S. Parragh, K. F. Doerner and R. F. Hartl: "Adaptive large neighborhood search for service technician routing and scheduling problems", Journal of Scheduling, Vol. 15, No. 5, pp. 579-600, 2012.

[4] S.N. Parragh, K.F. Doerner, R.F. Hartl and X. Gandibleux: "A heuristic two-phase solution approach for the multi-objective dial-a-ride problem", Networks, Vol. 54, No. 4, pp. 227-242, 2009.

[5] M. Schilde, K. F. Doerner, R.F: Hartl: "Integrating stochastic time dependent travel speed in solution methods for the dynamic dial-a-ride problem", European Journal of Operational Research, to appear, 2014.

[6] V. Schmid, K. F. Doerner, and G. Laporte: "Rich routing problems arising in supply chain management", European Journal of Operational Research, Vol. 224, No. 3, pp. 435-448, 2013.

[7] F. Tricoire: "Multi-directional local search", Computers & Operations Research, Vol. 39, No. 12, pp. 3089-3101, 2012.

Keywords

Integrated Problems in Production and Logistics, Supply Networks, Stochastic and Dynamic Problems, Multiple Objectives, Simulation-Optimization, Hybrid Optimization Techniques, Meta- and Matheuristics

Safety, Risk and Uncertainty Management

"From commercial and social point of view the expected impact consists in reduction of the exploitation costs, costs for the maintenance repair, risk to be in a complete failure state, losses due to damages and hazards."

Dmitry Efrosinin

Focus Line 4:

Mastering Complexity in Production and Communication Systems

Coordinator:

Assoz.Univprof. Dr. Dmitry Efrosinin
Institute of Stochastics

dmitry.efrosinin@jku.at
http://www.jku.at/stochastik

Research Focus

- Controllable Non-Reliable Stochastic Models of Queues and Degradation Units
- Evaluation of Reliability and Hazard Functions using Methods and Renewal Theory Algorithms
- Application of the Markov Decision Processes with Constraints for Controllable Systems
- Event-Based Dynamic Programming Approach for Optimization Problems

Vision

Safety, **Risk** and **Uncertainty Management** constitute essential part of reliability and safety engineering which emphasizes dependability or reliability on the random lifecycle or lifetime of a product unit or system. **Reliability analysis** focuses mostly on costs of failure coursed by system downtime, cost of spares, repair equipment, personal and cost of warranty claims. Safety analysis deals normally with preserving life and nature, and therefore considers particular system failure modes. In both cases common methods are used and they may require input from each other. The most important measure used to estimate reliability and safety is a reliability or risk function, which is normally a combination of probability to survive up to the given moment of time and severity of the failure incident occurring. Any approach to compute reliability or risk function in random domain is based on a certain stochastic model. Further we enumerate the main methods to perform safety, risk and uncertainty management. (i) Many technical and manufacturing systems subject to failures can be represented as a system (connection) of dependent or independent non-reliable components (units) whose reliability makes a contribution to the total reliability of the system. The **system reliability can be treated as a function of component reliability**.

Depending on practical applications the components can be with and without repair, the system can be with hot or cold reserves, the connection of the components can have a hierarchical structure. Based on connection structure and information about the relationship between the components it is possible to provide a fault tree analysis and estimate the importance of a certain component or subset of components for the system reliability and obtain an optimal decision policy about a necessity to provide a warranty service and maintenance repair. (ii) Another group of stochastic models are based on **parametric lifetime distributions**. In this case the main aim is to estimate aging and failure rate, confidence intervals based on **complete** and **incomplete data**. There are a number of statistical methods of Exploratory Data Analysis (EDA) for censored and grouped data, e.g. on basis of Maximum Likelihood Method, methods of time series analysis. (iii) Information about life time distributions can be implemented to develop **preventive maintenance models** which are very important in production research. By choosing a preventive maintenance scheme, engineers are usually interested in selecting the maintenance parameters, e.g. the maintenance period, in the optimal way.

To perform this task one needs normally to compare the expressions for long-run average costs or rewards for various maintenance periods. Mathematical techniques are based mostly on the **methods of renewal theory** and **reward processes**. The mostly used models belonging to this group are the **models of periodic replacement**, **age replacement** and **random choice of preventive maintenance periods**. In the previous models the lifetime of the system is usually treated as a transition time from absolutely new state to a complete failure state. In practice there are many systems subject to failures like a fatigue crack growth, degradation or corrosion. The corresponding stochastic processes will have in this case intermediate states before the system visits an absolutely failure state. In case of repairable model the system can be analyzed in a stationary regime, where the mean time between two successive failures, the availability of the system and average cost can be treated as optimization criteria in certain decision problems. Otherwise **stochastic processes with absorption** are appropriate models to evaluate the life time distribution on a one life cycle. (iv) An adequate formal tool for finding optimal maintenance policy for multi-dimensional, multi-state maintenance models is a **Markov-type process** with rewards or costs associated with the transition from state to state. In classical case of the continuous time Markov process the time between transitions is assumed to be exponential distributed with corresponding parameters. For practical applications a very useful generalization is a **semi-Markov process** with generally distributed time interval between transitions.

Stochastic modeling of reliability systems often contains many sources of stochastic uncertainty. It is related to the real variability of a parameter, which assumed to be random, e.g. the discharge of a river in a flood risk evaluation. To evaluate uncertainties a generic computational model can be used. It is necessary to define the input uncertainty in terms of n random variables X. Dependences between inputs can be specified by using copulas structure, i.e. if cumulative distribution function (CDF) is presented as a function of the marginal CDFs or using conditional distributions (Bayesian Networks). The output variable of interest can be linked to uncertain inputs through some function u. This function can be presented as analytical formula or as a complex finite element code. The function can have low or high computational costs, measured by its CPU time. **Uncertainty propagation** is the quantification of uncertainties in system output(s) propagated from uncertain inputs. It focuses on the influence on the outputs from the parametric variability listed in the sources of uncertainty. One of the main targets of uncertainty propagation is evaluation of the reliability function of the output. The commonly used propagation methodology is a sample-based technique with **Monte-Carlo simulation method**, spectral methods, e.g. quadrature-based methods like **Stochastic Collocation** (SC) and Galerkin-base approaches such as **Polynomial Chaos** (PC). Sampling methods compute statistics and Probability Density Function (PDF) by interrogating the parameter space. In SC and PC the moments are computed explicitly. We interpret SC and PC as approximate representations of the solution which depends continuously on the input random variables.

Finally, we generalize the main stages for safety, risk and uncertainty management of any technical complex system: identification of appropriate stochastic model (systems of components with parametric lifetime distributions, renewal processes, preventive maintenance models with periodic and age replacements, Markov and semi-Markov processes), parameter estimation based on complete and incomplete data (using EDA), uncertainty quantification (Bayesian approach, spectral methods), validation and verification of the model, interpretation of results.

Approach

Some wearing and aging models were in focus of many investigators in the framework of shock and damage models. The aging and degradation models suppose the study of systems with gradual failures for which multi-state reliability models were elaborated. In our research unit (Institute of Stochastics, JKU) to perform safety and risk analysis of aging and degradation systems we are working with special types of stochastic processes such as renewal processes with rewards, linear stochastic processes of time series models, Markov and semi-Markov decision processes, Hidden-Markov models and others. We are working mostly with such mathematical models as degradation and queueing systems. This section deals with a short overview of approaches used in our research.

Degradation systems with observable states. We have developed the methods for stochastic modeling of complex technical system subject to degradation, [2]. Degradation processes under study are assumed to be observable or some measure parameter can be associated with a process, e.g. signal of acoustic emission, measures of the gravimetric analysis and electromagnetic flaw detection. Two main types of systems are of interest. In first case the system consist of degrading units, which are assumed to be of a multiple use [4], i.e. after the complete failure it can be repaired. After the repair the degrading process starts again in an absolutely new state. The unit is supplied by a monitoring system and by a controller. The monitoring system gives the information about current degradation state and based on this information the controller makes a decision about a necessity to perform the preventive repair until the last degradation state is achieved. The control problem is studied in a stationary regime. In second case the degrading unit operates till the first complete failure [5]. It is assumed that the unit possesses of some initial (generally speaking, random) life resource. The real applications of the proposed degradation models which can be obviously useful in production research are the following: Corrosion processes of a unit with protective covering, damage process due to the fatigue crack growth, wear of a tool of machine-tools, wear of a plane bearing, discharge of an external load. Uncertainties: Number of levels in hierarchic system, dependencies between the system components and subsystems. Methods: Dynamic programming approach for Markov decision processes, value-iteration algorithm, Markov processes with absorption, and recursive methods of renewal theory.

Degradation systems with non-observable states. Different industrial processes need to be maintained to prevent breakdown. In many cases the real states of the degradation process are non-observable. In mechanical systems, noises and vibrations precede complete failure. Loss of performances reflects failures or technical defects. In computers, suspect pointer movements, loss of performances, application malfunctions like web browser may reflect virus presence on computer ans so on. This indirect information can be used to estimate the real availability state of the system. The effective approach and is the usage of Hidden Markov Models (HMM). Hidden process will fit to system or subsystem states of gradual failures and observations will be the mentioned indirect information. Therefore, HMM is an appropriate mathematical model for estimation of the availability indicator which can be used by maintenance controller to plan actions dynamically. This approach is used also for localization of mobile objects via Time Difference of Arrivals (TDOA) measure of the radio signal. Possible uncertainties: transition probabilities between non-observable states. Methods: Viterbi algorithm, Baum-Welch algorithm, EM-algorithm.

Degradation systems for Internet Security. The degradation systems with gradual and instantaneous failures can be used also for modeling of the attack process consisting of several attack paths, e.g. buffer overflow, Man-in-the-Middle, SQL Injection, traffic sniffing and so on. It is proposed a state-based model consisting of a set of states and a set of transitions. Some of these states represent the specific security states: security situation and failure situation. The dynamics is modeled by means of a semi-Markov process. The following security measures like mean time to failure (MTTF), mean time between failures (MTDF), type of security failure, transition probabilities can be evaluated. Uncertainties here are: type, frequency, intensity and duration of individual attacks. Methods: steady-state and transition analysis of semi-Markov process.

Non-reliable queueing systems. The queueing systems are well known mathematical models for description of service dynamic processes in production lines, supermarkets and warenhouses, computer and telecommunication systems, data transmission in local area networks and Internet, requests in databases and software. Queueing system is a system in which customers randomly come to be served. The simplest queueing system consists of one server that serves customers with respect to a first-come-first-served (FCFS) discipline and a waiting line or queue (ordinary queue) where customers wait before receiving service if they cannot be served immediately upon arrival. In our research we have studied an astonishingly large number of variations. The systems with more than one server that could serve at the same speed or different speeds. The server can fail in some random amount of time and it can be switched on/off. Besides the queueing systems with an ordinary queue, there are queueing systems with a retrial effect, i.e. if upon arrival of a new customer a server is busy, the customer leaves temporarily the service aria and joins a so-called “orbit” where it retries to occupy the server in some random amount of time. By mean of queueing systems we have proposed performance and reliability analysis as well as solved different optimization problems for different real systems, like Wireless Sensor Networks (WSN) [6], group of servers with different types of processors as a consequence of system updates [7], nodes in telecommunication networks with links of different capacities and availability [1], multi-processor systems with processors of different throughput and electric energy demand [3], etc. Methods: steady-state analysis of Markov decision processes, transition analysis, analysis of first passage times, matrix-analytic approach for the quasi-birth-and-death process (QBD).

We believe that combination of the approaches, methods and models developed at the Institute of Stochastics with statistical methods of data mining and Exploratory Data Analysis will see much more significant practical applications in the field of production research since they were developed in such a way to be more familiar to reliability engineers, operations research analysts, computer science people and others.

Impact

The main **scientific impact** consists in specification of an appropriate stochastic model for risk and safety analysis based on available information about structure, hierarchy and internal dependencies in the system. The available statistical data can be used to estimate the model's parameters and to confirm acceptable quality level of the model fitting.

The potential **technological** and **industrial impact** includes understanding of the nature, influence and rank importance of uncertainty assessment needed for risk and safety management of complex technical system. For the specified mathematical model we may propose appropriate effective methods and algorithms with small computational time to evaluate performance and reliability measures of interest. For the certain model with given cost structure a number of optimization problems with respect to certain optimization criterion can be formulated and solved, e.g. optimal maintenance and replacement policy, optimal system structure, operation and design, number and usage policy of reserves, identification of weak points of the system and so on.

From **commercial** and **social** point of view the expected impact consists in reduction of the exploitation costs, costs for the maintenance repair, risk to be in a complete failure state, losses due to damages and hazards. The studied optimized reliability models under optimal policies were superior in performance and reliability up to 30% comparing to non-optimized models. In general, the performance and reliability characteristics of non-reliable system under study can be considerably improved via optimal decisions which can in its' turn make a competitiveness of production firms sufficiently higher.

References

[1] D. Efrosinin: "Queueing model of a hybrid channel with faster link subject to partial and complete failures", Annals of Operations Research, Springer, pp. 75–102, 2013.

[2] D. Efrosinin, M. Farhadov: "Optimal control of a system with gradual and instantaneous failures", Reliability, Vol. 1, No. 29, pp. 27–41, 2009.

[3] D. Efrosinin, J. Sztrik: "Performance analysis of a two-server heterogeneous retrial queue with threshold policy", Quality technology and quantitative management, NCTU Publication Press, Vol. 8, No. 3, pp. 211–236, 2011.

[4] D. Efrosinin, V. Rykov: "Degradation models with random life resources", Communications in statistics – Theory and Methods, Tailor and Francis, Vol. 36, pp. 398-407, 2010.

[5] D. Efrosinin, V. Rykov: "On optimal control of systems on their life time", Recent advances in system reliability, Springer, pp. 307–319, 2012.

[6] D. Efrosinin, A. Winkler: "Queueing system with a constant retrial rate, non-reliable server and threshold-based recovery", European Journal of Operational Research, Elsevier, Vol. 210, No. 3, pp. 594–605, 2011.

[7] J. Sztrik, D. Efrosinin: "Tool supported reliability analysis of finite-source retrial queues", Automation and Remote Control, Springer, Vol. 71, No. 7, pp. 88–91, 2010.

Competencies

Institute of Stochastik has a long-term experience in stochastic modeling in different fields of science, particularly in safety, risk and uncertainty engineering. During our activity we try to combine fundamental research results such as theoretical properties of the optimal control policies, methods and algorithms for calculation of the performance and reliability measures with corresponding practical applications.

Our research unit was supported by the number of research grants from the Russian Fund of Fundamental Research (RFFR), e.g. **Stability and Performance Analysis of the Telecommunication Networks**, **Performance Analysis of the LANs Based on the Regenerative Approach**, the Austro-Hungarian Action (ÖU), e.g. **Performance analysis of networks and protocol**, **Mathematical Model of a Call-Center with Self-Service Facility**, the Austrian Research Promotion Agency (FFG), e.g. **BigData and Ontology Driven Process Mining for Knowledge Based Optimization of Agricultural Production**, **Statistical behaviour analysis of farm animals**, **Localization in wireless-Sensor Networks** and direct industrial cooperation, e.g. **Cluster analysis based on eigenvectors** (PROFACTOR, Steyr), **Statistical analysis of data obtained by REM/EDX-measure system for different sorts of steel** (VOEST ALPINE, Linz), **Statistical analysis of morbidity** (MAN AG, Steyr), **Statistical analysis and improvement of the quality of heat supply** (LINZ AG, Linz), **Assessing the variability of acceleration factors in the load matrix** (AVL, Graz), **Mathematical model for the car rent firms** (EUROPCAR, Wien).

The detailed information about competencies of the Institute of Stochastics as well as a list of publications and projects can be found at **http://www.stochastik.jku.at.**

Proponent

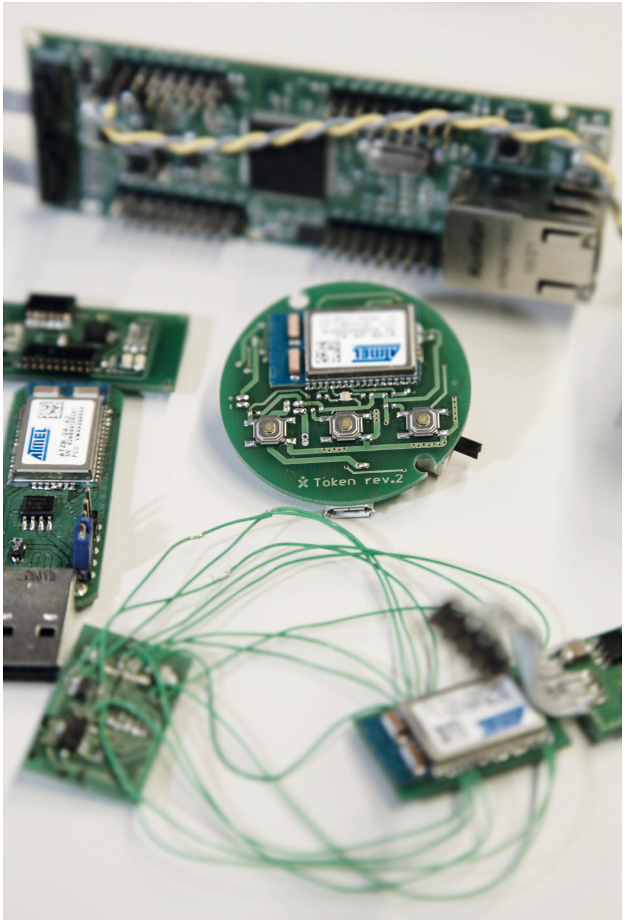
Assoz.Univprof. Dr. Dmitry Efrosinin
Institute of Stochastics

dmitry.efrosinin@jku.at
http://www.jku.at/stochastik

Keywords

Reliability and Safety Engineering, Preventive Maintenance Models, Markov-type Processes, Non-Reliable Queueing Systems, Degradation Systems

Cyber-Physical Products



"We understand Cyber-Physical Products as physical products that are linked to their abstract presentations and control processes in the 'digital world' via embedded ICT electronics."

Alois Ferscha

Focus Line 4:

Mastering Complexity in Production and Communication Systems

Coordinator:

Univ.-Prof. Mag. Dr. Alois Ferscha
Institute of Pervasive Computing

ferscha@pervasive.jku.at
www.pervasive.jku.at

Research Focus

- "Co-Evolution" of Society and ICT Socio-Technical Systems
- Products for Needs Demand Driven Supply Chains and Batch Size 1 Production
- Enabling Technologies for Self-Organizing Products Markup Languages and Ontologies for Product Self-Description
- Multi-Sensor Fusion and Machine Learning Based Collection and Synthesis of a "Product Memory"

Vision

One of the most profound socio-technical phenomena of the last decade is the increasing blurring of boundaries between the digital and the physical world. Continuing trends in (i) **miniaturizing** Information- and Communication Technology (**ICT**) (microelectronics, system-on-chip technologies, ultra compact memory systems, micromechanics, nanowires and nanotubes, etc.) and (ii) the **exponential growth and globalization of communication infrastructures** (out of the estimated world population of 7.017 billion people some 2.405 billion Internet nodes (http://www.internetworldstats.com on February 26, 2014), and more than 7.424 billion (2G and 3G) SIM enabled mobile connections (including M2M) were registered by the end of 2013 (ATKearney, The Mobile Economy 2013) have opened an unexpectedly wide spectrum for possible future scenarios of a "**co-evolution**" of society and ICT in general, and commodities (goods, products, consumables) and consumption in particular. This is fundamentally changing the way how people act, communicate, or even think, and consequently also how human wants and needs emerge, and how they are announced and satisfied. Foreseeably, future notions of "**products**" (anything that is made available for sale, including commodity services) will redefine the principles of demand and supply, and reverse traditional supply chains from a "produce then sell" to a "**sell then produce**" paradigm. Indeed, we evidence already today **demand driven supply chains** and **batch size 1 production**, mediated via the WWW (NIKEiD, BMW i3).

To address such future notions of products with appropriate micro- (life cycle of an individual product) and macro-level (manufacturing, use of resources, energy, markets, environment protection) processes and policies, we have to extend the body of todays supply chain frameworks beyond the pure physical existence of a product. The process coverage has to spawn from the very immaterial state of a product being just a customer "idea", or "desire" or "need" at the lower end of the spectrum, up to the possibly again immaterial state of a product recycled back to raw material at the upper end of the spectrum. In a metaphoric language we could say that **products co-exist in the immaterial and in the physical world**, with the immaterial lifespan (usually) extending far beyond the material lifespan. This vision statement proposes a "cybernetic" integration of both the material and immaterial sides of a product, embracing the whole product lifespan.

In the scientific literature, Cyber-Physical Systems (CPS, UC Berkeley 2007) are referred to as integrations of computations (digital world) with physical processes (physical world). Borrowing from CPS, we understand **Cyber-Physical Products** (**CPPs**) as physical products (commodities, things) that are linked to their abstract presentations and control processes in the "digital world" via embedded ICT electronics. The embedded sensors, computers, actuators and communication technologies monitor and control the physical processes the product is engaged in, usually with feedback loops where physical processes affect control processes and vice versa. CPPs interact locally, spontaneously and autonomously with other CPPs in the physical and the control domain. Groups, flocks or large collectives of CPPs potentially exhibit a behaviour that does not trivially follow from the behaviours of the individual entities, indicating properties typically observed in **complex systems** (i.e. condensed matter systems, the immune system, road traffic, insect colonies or social networks on the Internet).

This vision statement proposes research on CPPs as (i) a new paradigm for understanding the emergence of human needs and demands, (ii) the close (ICT mediated) coupling of product related data and control processes to physical products and physical process, and (iii) the self-management of all kinds of interactions of physical products (manufacturing, logistics, self exposure, self explanation, process embedding, life cycle management, recycling) throughout the whole product lifetime.

We aim at the design and provisioning of **key enabling technologies** allowing for the development of **self-organizing products**, including mechanisms to implement (i) markup languages and ontologies for **product self-description**, (ii) multi-sensor fusion and machine learning based collection and synthesis of a "**product memory**", (iii) **goal oriented reasoning**, self-configuration and self-management of products in **complex systems ensembles**, and (iv) **P2M** (product to machine), **P2P** (product to product), **P2C** (product to consumer), **P2B** (product to business) and **P2E** (product to environment) **interactions**.

Early visions of opportunities for next generation products have been created in the context of the FP6 and FP7 EU research strategies: "Products with totally new capabilities will become available for general use, dreams such as intelligent cars, non-invasive health monitoring and disease prevention, homes sensitive and responsive to the needs of the persons living in it will become available to everybody. We will get better control of our health and environment, and over the quality of our food and our air, ensure better utilization of energy and other basic resources, we will be able to recognise diseases even before symptoms appear, and we will be able to be fully mobile and at the same stay constantly in touch with everybody..." (ENIAC, ISTAG 2009). Although ambitious European research has addressed many of the issues raised by those dreams (see also my proposal for research on "Autonomic Products" in 2005, ftp://ftp.cordis.europa.eu/pub/ist/docs/fet/ie-jan05-sac-6.pdf), we are far from that reality envisioned by the ISTAG group.

Approach

Some ten years of Pervasive Computing research have created a critical momentum towards both the technological feasibility, as well as the industrial viability of CPPs [1]. This is evidenced by the evolution of autonomous ICT systems. The first generation of ICT aiming at autonomous system behaviour was driven by the availability of technology to connect literally everything with everything (wired and wireless data communications). "**Networks of connected Things**" emerged, forming communication clouds of miniaturized, cheap, fast, powerful, "always on" systems, enabled by the massive availability of miniaturized computing, storage, communication, and embedded systems technologies. Special purpose computing and information appliances, ready to spontaneously communicate with one another, sensor-actuator systems to invert the roles of interaction from human to machine (implicit interaction), and organism like capabilities (self-configuration, self-healing, self-optimizing, self-protecting) characterize this generation - popularly referred to as the "Internet of Things" (IoT).

The second generation of autonomous systems inherited from upcoming multi-sensor based machine learning, recognition and knowledge processing technologies, making systems e.g. situation-/context-aware, self-aware, activity-/user-aware, energy-aware or even socially-aware [6]. This generation reframed autonomous behaviour to be based on knowledge (knowledge based sensing/monitoring of the environment, knowledge-based planning, knowledge-based acting). One result out of this course of research have been "autonomic elements", autonomous entities able to recognize context, to build up knowledge, to self-describe, self-manage, and self-organize.

The notion of "**Ecosystems of aware Things**" emerged, built from collective autonomic elements interacting in spontaneous spatial/temporal contexts, based on proximity, priority, privileges, interests, offerings, environmental conditions, etc., giving raise to "**Aware Products**" [3,4]. Today, a third generation of autonomous systems is emerging, building upon connectedness, knowledge and awareness, and attempting for a **semantic interoperability** of entities in large scale, complex, orchestrated, cooperative configurations. Such systems are also referred to as "Ensembles of Digital Artefacts" (FP7 FET), or "Socio-technical Fabric" [5]. A real world example of such a complex society-technology configuration would be the "ensemble" of 1012 -1013 "things" or "goods" traded in markets worldwide, related to 109 human beings, which in turn are interacting via 109 personal computers and 109 mobile phones connected to the Internet, mobilized with 108 cars, and creating digital content with 108 digital cameras, etc. Megacities with 107 citizens, the community of 108 Facebook users, the repository of 108 videos on YouTube and 107 pieces of music on last.fm, together with their user communities would be further examples. In summary, indicative to such complex socio-technical systems is (i) their scale beyond 106-107, (ii) entities (individuals, things, agents, objects) continuously acting and reacting to what the other entities are doing, (iii) the system control being highly dispersed and decentralized, and (iv) (coherent) behaviour arising from competition and cooperation among the entities, so that (v) the overall behaviour of the system is the result of a huge number of decisions made and interactions performed every moment by very many individual entities.

Following the above argument, we understand **CPPs** as being part of **dynamic**, **complex interaction ensembles** during their whole lifetime (demand/needs ensembles, manufacturing ensembles, logistics ensembles, sales ensembles, consumption ensembles, use and maintenance ensembles, recovery and recycling ensembles, etc.), within which they have to **sense**, **reason** and **act autonomously**. The manifestation of a rational for autonomous "reasoning and acting" is not trivial, as products may find themselves in (i) **self-adaptive ensembles**, which evaluate their own global behaviour and change it whenever the evaluation indicates that they are not accomplishing what they were intended to do, or do so only at low levels of quality/performance, or in (ii) **self-organizing ensembles**, typically composed of a large number of entities that interact locally according to typically simple rules, in order to attain a certain "desirable" global behaviour. In both cases, strategies leveraging **micro-level behaviour** that is indicative to yield desired **macro-level outcomes** are in charge, but very hard to find.

In order to implement **CPPs**, a "stick-on" [3], networked embedded systems approach is proposed, linking physical real world objects (things, products, etc.) to digital representations and control processes by attaching a (physical) "**Smart Label**" to the object. We refer to a Smart Label as a low-power, low-weight, tiny scale, low-cost, extremely miniaturized microelectronics platform. On the **hardware** side a Smart Label integrates computing, storage, wireless networking, and versatile sensor and actuator components. On the **software** side it executes a low memory footprint, virtual machine like runtime environment, implementing (i) mechanism of adaptive self-description in standardized meta-data format (including the product memory), (ii) a proxemic interaction engine (spontaneous interaction), (iii) a multi-sensor, multi-purpose, machine learning based recognition framework (sensing), (iv) an opportunistic, goal-oriented reasoning engine (planning and decision making), and (v) a self-adaptive, self-managed behaviour control unit (acting). (See our reference implementation, the "IPC token" platform, now in its 3rd generation.)

Among the research challenges for Smart Labels are (i) reliable, secure, trustworthy and real-time **indentification** and **authentication** mechanisms (to surpass the limitations of RFID, NFC, AutoID based systems, etc.), (ii) **miniaturization** and **embedding** of **sensors** like positioning units, accelerometers, gyroscopes, magnetometers, seisometers, thermo- and hygrometers, anemometers, gasmeters, MEMS microphones, olfactometers, radar-, lidar- ultrasonic detectors, doppler radars, geiger counters, etc. and **actuators** like photo switches, tilt switches, Reed switches, piezo- and pyroelectric actuators, etc., (iii) multi-sensor based **recognition frameworks** for localizing and positioning, environment and situation recognition, use-pattern recognition, attention and emotional state recognition (active learning, reinforcement learning, transfer-learning to surpass the limitations of unsupervised methods), novelty detection and context prediction, (iv) **semantic modeling**, markup languages (e.g. PML, SensorML, schema.org/thing), ontologies (e.g. GoodRelations, eClassOWL) and standards (EPCglobal, GS1), (v) **product memory** management and **goal oriented decision making** (GRL, extending traditional PRS and BDI based reasoning engines towards more anticipatory mechanisms of action control), and (vi) the **disentanglement** of the complex relationships between local interactions and global effects, in order to obtain **operational controls** to induce behavioural change.

As a research method I attempt to employ a combination of **theory driven analytics**, computational modeling/simulation, HW/SW platform **prototyping**, together with **hypothesis driven experimental research** (using both experiments with deployed label prototypes and the collected field data, as well as **very large scale ABM** (106 agents) **high-performance simulations** at the 2048 core, 16TB NUMA supercomputing platform SGI Altix UV), and **user studies**. I believe in -and have exemplified in the past- a **synthesis** of **theory driven** and **data driven approach** of research: in the theory driven approach we inherit from established theoretical bodies (information theory, complex systems theory, machine learning theories, behaviour theories, collective choice theory, social systems theory, etc.), based on which hypotheses are formulated and data sets are collected (on purpose) to evidence those hypotheses - ultimately, of course, to foster and strengthen the evidence for such (pre-existing) theories. In the data driven approach we deduced insight from mining pre-existing data sets (Big Data) with specific mining techniques (statistical clustering, classification, regression-/factor-analysis, sequence-/pattern-mining), potentially giving raise for new theories.

Impact

In the **Complex Systems** domain, this research is expected to create **scientific impact** in understanding the fundamental principles of autonomous sensing and reasoning, knowledge based self-organization, and the relation of local individual interaction to collective adaptive behaviour in very large scale (107 -109) socio-technical systems. Theory driven (ABMs and high performance simulation) and data driven (deployment of prototypes and reality mining) methods will evidence our findings. In the **Networked Embedded Systems** domain, the integration of sensing, reasoning and acting mechanisms, implementing self-awareness, self-management, goal-oriented behaviour, and dynamic adaptation will create novel design and operational principles for future, massive scale ICT systems exhibiting collective intelligence. In the **Pervasive Computing** domain we expect to achieve pioneering models and reference implementations of a planetary scale coordination architecture for globe spanning product eco-systems. **Opportunistic Sensing** combined with **Active Learning** / **Transfer Learning** based recognition chains may significantly extend the state of the art in machine learning, and advance feature extraction methods and classification algorithms for very resource (compute power) constrained execution platforms.

The potential **industrial** and **commercial opportunities** of a Smart Label based digital/physical integration -by embracing also the im-material product life stages- go way beyond the opportunities of horizontal and vertical integration of manufacturing systems, and traditional supply chain management. It has become very clear over the few years of experience with state of the art label technology (EAS, RFID transponders, Chip Labels, Thin Film Electronics, Visual Markers, etc.), cannot go beyond pure identity management - in controlled environments. A second generation of label technologies is under way as we speak (e.g. Poken, nTag, NFC Stickers, ZigKey, or iBeacons, a March 2014 announcement of Apple Inc.), with improved wireless capacities, but no/very limited on-platform capabilities.

The potential **societal impact** and opportunities of CPPs are countless, ranging from value sensitive product design, product individualization, Web of Needs and need based marketplace infrastructures, need driven manufacturing, self-explaining / attention-aware / supportive products, (emotional) consumer-product engagements, optimization of use of resources / logistics / use-patterns / waste management / recycling strategies, conservation of (natural) resources, etc., - ultimately also fostering a human centered, flourishing symbiosis of society and technology.

References

[1] A. Ferscha: “20 Years Past Weiser: What‘s Next?”, IEEE Pervasive Computing, Vol. 11, No. 1, pp. 52–61, 2012.

[2] A. Ferscha, N. Davies, A. Schmidt and N. Streitz: “Pervasive Socio-Technical Fabric”, Procedia Computer Science, Elsevier B.V., Vol. 7, pp. 88–91, 2011.

[3] A. Ferscha, et al.: “Peer-it: Stick-on solutions for networks of things”, Pervasive and Mobile Computing, Elsevier B.V., Vol. 4, No. 3, pp. 448–479, 2008.

[4] C. Holzmann and A. Ferscha: “A framework for utilizing qualitative spatial relations between networked embedded systems”, Pervasive and Mobile Computing, Elsevier B.V., Vol. 6, No. 3, pp. 362-381, 2010.

[5] A. Ferscha, K. Farrahi, J. van den Hoven, D. Hales, A. Nowak, P. Lukowicz, and D. Helbing: “Socio-inspired ICT. Towards a socially grounded society-ICT symbiosis”, European Physical Journal ST 214, pp. 401–434, 2012.

[6] P. Lukowicz, A. Pentland and A. Ferscha: “From Context Awareness to Socially Aware Computing”, IEEE Pervasive Computing, Vol. 11, No. 1, pp. 32–41, 2012.

Competencies

My operational research units (JKU Institute of Pervasive Computing, JKU Research Studio) are well interwoven with international EU funded Pervasive and Ubiquitous Computing projects in FP6 and FP7.

The recent research work is allocated in the domain of **Recognition Architectures and Opportunistic Sensing** (FP7 FET projects OPPORTUNITY, SOCIONICAL), **Networked Embedded Systems** and **Energy Efficiency** (FFG Projects PowerIT, Power-Saver, ZiT Project Sports Community Token), **Human Computer Confluence** (FP7 FET project HC2), **Complex Systems** and **Coordination Architectures** (FP7 FET project SAPERE), **Fundamentals of Collective Adaptive Systems** (FP7 FET Projects PerAda, FoCAS, SAPERE), and **Value Sensitive ICT Design** (FFG Projects Raising Attention, DISPLAYS, 360 Light).

Translational research cooperations with industrial partners range from manufacturing, to network operators, consumer electronics vendors and media corporations (Red Bull Media House, Energie AG, Silhouette AG, Google Glass, Sembella, SIEMENS, IBM, Telekom Austria, ONE/Orange, VCM, WRC, etc.).

I serve as a permanent consultant for the EU ICT research strategy (EC DG CONNECT, Unit FET, Future and Emerging Technologies), with a strong tradition in identifying and soliciting basic research problems and strategic research fields emerging from the evolution of the global information and knowledge society (see e.g. **FET Whitebook Pervasive Adaptation**, http://www.pervasive.jku.at/fet11/RAB.pdf, or the **FET Whitebook Human Computer Confluence**, http://www.pervasive.jku.at/hccvisions/book/#home).

The Institute of Pervasive Computing runs outstanding, state of the art laboratory equipment and experimental infrastructures, e.g. the Sensor Lab (Geolocation Sensors, Accelerometers, Gyroscopes, Position/LocationTrackers, Ultrasonic Sensors, Depth/Thermal Imaging, Pressure Sensors, MEMS, Bio-Signal Sensors, etc.), the Display Systems Lab (HDTV DLPs, Wearable Displays, Eye Trackers, Multiscreen HD LEDs, Tactor/Olfactory Displays, Smart-Watches, etc.), and the 360 Lab (360 Video Sensors, Capturing, ProcessPipeline Tools, 360 broadcasting technology).

Proponent

Univ.-Prof. Mag. Dr. Alois Ferscha
Institute of Pervasive Computing

ferscha@pervasive.jku.at
www.pervasive.jku.at

Keywords

Networked Embedded Systems, Complex Systems, Self-Organisation, Collective Adaptive Systems, Internet of Things

Man-Machine Symbiosis

"Towards a fruitful symbiosis among man and machines we are challenged to develop "aware systems", i.e. systems that understand the physical situation they are operated in ("context-aware systems"), systems being aware about the user and his activities ("activity-aware systems"), systems being aware about the social state ("socially-aware systems"), and even about the amount of allocated human attention ("attention aware systems") and emotional expressions ("emotion-aware systems") of the user."

Alois Ferscha

Focus Line 4:

Mastering Complexity in Production and Communication Systems

Coordinator:

Univ.-Prof. Mag. Dr. Alois Ferscha
Institute of Pervasive Computing

ferscha@pervasive.jku.at
www.pervasive.jku.at

Research Focus

- Aware ICT (Context-, Activity-, Socially-. Attention-, Emotion-Aware Systems)
- Human-centered Man-Machine Interaction
- Collaborative cooperation between workers and production machines

Vision

Due to the technologic progress collaborative machines find increasing application in diverse production scenarios in which machines and humans are required to work hand in hand. This mode of operation allows a higher productivity, better error management as well as resource-efficient, competitive production environments [1] and sustainable production [2]. On the other hand, extremely short product lifecycles, frequent changes in product characteristics and resulting flexibility requirements prohibit a further automation of industrial production with traditional production machinery, as the existing full-automated processes reach the limits of profitability. Approaches towards expanding the automation to highly complex manufacturing and assembly processes are facing technological feasibility issues. At the same time, complex production processes and machines increase requirements on workers regarding specialization and know-how.

A new generation of collaborative machines

Especially complex assembly tasks and the production of small lot sizes are hard to automate, as many tasks cannot be efficiently carried out without human assistance. The exploration of innovative cooperative working areas for humans and machines requires the development of inherently safe machines which do not present any dangers without the protection of separating instalments. Currently about 10% of industrial production are penetrated by machines and robots. Expanding this market can only be realized via the integration of collaborative production infrastructure.

Man and Machine united in the production of the future

Future applications are supposed to unite the distinctive abilities of industrial robots regarding strength, accuracy and repeatability with the flexibility, fine motor skills and intelligence of the human worker in collaborative environments which hold diverse advantages and new potentials via sensing of psycho-physiological parameters. This physical interaction between human and machine allows the required efficient realization of processes in manufacturing with increasing variety. Furthermore, direct interaction with context-sensitive robots will reduce production costs not only regarding required space but also in terms of efficiency, as several tasks can be carried out simultaneously [3]. This implies approaching the optimal level of automated production which - with respect to the requirements on flexibility, production of minimum lot sizes and complexity of tasks - will considerably fall below 100% and will make the human worker indispensable even in a further automated future [4], [5].

Challenge I: Cognition-sensitive machine control

The enormous flexibility in production, which is linked to the aspired mass-individualization, represents a contradiction that can only be resolved via a direct cooperation between man and machine in the industrial production. Such collaborative activities require a generation of interactive and cognition-aware production infrastructure which has an intrinsic self-awareness of their environment, there-in situated human workers and their activities, intentions and attention distributions to enable an intuitive collaboration with humans in a shared workplace. Hence, the main research question is: Can we create an intuitive, supportive and optimized human machine interaction in the scope of industrial production processes?

Challenge II: Understanding Human Attention

While considered a mental variable that could not be quantified and measured in metric terms in the early nineteen-hundreds, human attention has constituted a fundamental element of psychological research since then. Today, everyone has an intuitive understanding of what attention is, how it can be assessed and how it impacts perception, memory, expectation, awareness, relevance, decision-making, and other behaviours. Yet, there is hardly any human capacity as complicated to describe. Competing sensory stimuli which are controlled via top-down (conscious) and bottom-up (unconscious) sensory and perceptual processes, and the allocation to their respective importance makes attention hard to parameterize or even to measure. Formalizing human attention is extremely difficult, since it not only involves evidence based research (like the analysis of measurable, indicative signs of attention), but also theory based research of human cognitive capacities. We are convinced that it is necessary to attempt for formal attention models as a synthesis of these two research methods.

Our first step towards human attention models, will attempt to understand how individuals perceive information accessed via ICT in manufacturing processes. At the same time we will look at established attention models developed in cognitive and social sciences, and will try to validate them with datasets drawn from experiments in real world settings, using the research methods of reality mining and Big Data analysis [6]. The synthesis of the two respective model categories will thus represent the foundational underpinning for formal models of individual and collective attention, combining the rich body of cognitive models from neuroscience and artificial intelligence, with evidence from real world experiments.

Approach

The Evolution of “Aware” ICT Today’s ICT has experienced a stunning evolution from a single-computer-per-person ratio to a massive load of traditional, wearable and embedded computers [7] which are distributed and interconnected over the whole globe, creating unimaginable amounts of data beyond any human processibility. Still, early accustomed interaction principles from the 1980’s have not evolved along the sheer numbers of available devices, as most interaction concepts still expect a single-person relationship [8] based on explicit in-and output, demanding the user’s full and undisturbed attention. Yet, there are vivid approaches to overcome these shortcomings in human computer interaction and usability design.

In recent years, Ubiquitous and Pervasive Computing [9], [10],

[11], research has shaped a wide-spanning research area at the borders between computer science, behavioral science and social sciences. Approaching a human-computer relationship in which the human is not reduced to a mere consumer of presented loads of information requires computers to become "aware" of what information is relevant and useful for the respective person, in the current situation, activity and environment. Such awareness is based upon multi-sensor systems equipped with machine learning, recognition and knowledge processing algorithms to assess contextual information and provide personalized services.

As "context" is a very multi-layered and complex term, the first steps towards "aware ICT" over the past decade started with systems being aware about the physical situation they are operated in ("context-aware ICT" [12]), to later trying to asses information about the user and his activities ("activity-aware ICT"). Recent trends include information about the social state of the individual ("socially-aware ICT" [6]), and even the affective state of a user ("emotion-aware ICT") as well as the interpretation of connected devices as a socially collaborating collective ("Socio-Inspired ICT" [13]).

Current (international) research initiatives (H2020: Excellent Science: Human Brain Project, FET PROACT 2, Industrial Leadership: ICT 1, ICT 2, ICT 10, ICT19, ICT 20, ICT 22; Societal Challenges: SC 7, SC 1, EURO 6) aim at enabling a true awareness and modelling of the user as a person, including feedback on his state of mind, level and focus of attention, thus closing the still open interaction feedback loop towards a human-human interaction quality in human-computer interaction. In this context, current trends indicate the establishing of a so-called cognition-aware or attention-aware ICT to shape the flow of information aligned with the cognitive attention capacity of the recipient.

From implicit interaction to Cognitive Control Models

A crucial prerequisite of an ICT system to be "aware" is the ability to autonomously sense and perceive, recognize, and even anticipate phenomena and their consequences in the context of its operation. Attention- or Cognition-Aware Systems (AAS) require a fundamental understanding and modelling of the user, his situation, activity and state, as well as awareness of the user's perception of presented information. This implies a fundamental paradigm shift towards a truly user-centered technology which is oriented at optimizing user value and usability instead of the established maximization of information throughput.

Implementing algorithmically advanced and computationally efficient software-frameworks for multi-sensor based recognition chains is crucial for the acceptance of aware ICT systems. AAS require a highly-developed, sensor-based, autonomous-cognitive machine control system. Cognitive user models represent the most advanced approach to perception-based control of any kind of interactive system, be it medical information systems, automotive control devices or industrial manufacturing infrastructure [14]. Cognition-aware systems are able to monitor complex human cognitive states and context information which then can be translated into simple control commands on machine language levels [15] and which can dynamically adapt to human abilities [16]. Yet, the successful modelling of mental states and intentions requires a fundamental understanding of cognitive processes and cognitive demands in the respective working environment [17, 18].

The prerequisite of modelling cognitive states is an encompassing assessment of context and situation information via automatic observation of user and environment, a process which is well established in ubiquitous and pervasive computing [19]. Context-aware systems employ numerous different sensors to assess descriptive and expressive parameters to describe relevant situational information of a scene (location, time, weather, social situations, people, objects, activities, relations, etc.).

The underlying motivation of this initiative is the development of a sensor technology which enables industrial machinery to interact with their environment and provide assistance on a sophisticated level to neither under- nor overload the industrial worker. The aspired sensor system enhances current interactive systems that usually at best are restricted to mere presence detection, with a cognitive analysis of ongoing activities, perception levels and cognitive load of workers in their close environment with the ambitious goal to create a productive, ergonomic, pleasant and most of all safe working environment for the human worker. This includes a conclusive interaction concept which not only is based on smart machine control, but allows adaptive interaction feedback as well as information transfer up to training on the job solutions to create an optimal level of cognitive load.

General Approach

The assessment of user engagement and attention distributions represents a sophisticated task, yet, we are confident that the combination of different sensorial modalities will be the key to a successful assessment and interpretation of user data. Hence, we approach this challenge via the prototypical implementation of a multi-sensor interaction platform as a first realization of a future cognitive machine- and robot control. This platform consists of four components (i) Cognitive Modelling of users (ii) evaluation of Experience and Skill Levels for selection of assistance and interaction mode (iii) Knowledge Transfer Database as stock of reference processes for (iv) Deployment of machine control commands and interaction feedback and assistance information to the interacting worker.

With such a sensor-actuator system, we are confident to significantly improve usability and comfort for the user as well as productivity, safety and knowledge management for the industrial partners, thus approaching a true collaborative working relationship between human workers and industrial infrastructure. In summary, thus, this research initiative, we address fundamental issues of human-machine interaction: (i) cognitive issues: perception, awareness comprehension and cognitive models. (ii) technologic issues: safety, reliability (sensors, implementation), natural interaction (iii) ethical issues: acceptance, limits of automation, level auf autonomy, responsibility.

The measurement of cognitive load and interaction effectiveness needs to be based on experimental approaches [20] in which we will measure psycho-physiological responses and parameters in addition to general situation- and activity assessment. The goal is twofold: (I) direct use of captured and modeled cognitive state as input for machine control and (II) optimized support of workers based on the estimation of experience & skill levels with suitable support via interactive feedback.

Cognition Modelling

Computational cognition or attention models not only hold a formal description but can be tested empirically [21]. Our goal is to develop models of user behavior (re)actions based on real-time psycho-physiological responses based on the combination of sensing modalities. Via analyzing empirical training data, we believe we will be able to isolate relevant factors for the creation of computational model of cognition with increasing complexity. The creation of such a model requires mapping of the complex multimodal physiological input on one side to a well-defined set of interaction events and statuses on the other. The evaluation of the developed models must ensure that the resulting interaction control is understandable and predictable by the user. Starting point of the developments will be available models of attention from the literature (SEEV [22], saliency maps [23], etc.)

Impact

ICT enables a fundamental automation of all fields of industrial production and thereby an increase in productivity and flexibility up to lot size 1 with a simultaneous decrease of production costs. This optimization of manufacturing represents a central aspect in the race for future competitiveness of the western production locations, hence is connected to an immense development initiative in research as well as industrial production and service provision [24].

The vision of the production of the future includes the abandonment of diffuse marketing expectations, towards an individualized production in minimal lot sizes or individual production which is driven by actual verbalized customer needs. This is expected to reduce production costs, allows customization of products for the individual in the framework of a mass production infrastructure, optimizes use of required material resources and minimizes merchandising risk as production is aligned to actual needs.

The key objective and unique selling point in this initiative is enhancing any kind of (especially handicraft-based) industrial production with cognitive (attention and activity-aware) controls.
Beyond the automation of previously manual processes, this will also include already (semi-) automatized production processes which are supposed to be modernized via innovative forms of interaction and hence the elimination of barrier fences and reduced costs via gains in space and flexibility [25]. Furthermore, the potential of the collaboration of several different robots in the same production process offers further advantages in terms of increase in production efficiency.

The automation of currently manual processes via collaborative technologies allows a significant increase of production rates and efficiency. This especially applies to complex product assembly processes which are characterized via heavy component parts and complicated installation procedures. This allows the optimal combination of the individual, supplementary abilities of humans and machines (intelligence, fine motor skills, context comprehension vs. strength, reliability, repeatability). Such a technological support reduces physical, gender-related differences and simplifies gender-independent employment in industrial production. Due to the aspired modular approach, the applicants offer a cost-effective opportunity for upgrading existing production infrastructure, thus especially approach SMEs that usually are reluctant regarding innovations due to the barriers of usually high reacquisition costs.

The aspired clientele of the technology to-be-developed encompasses any company involved in industrial, automatable production. Besides operators of automatic production machinery, manufacturers of industrial robots represent highly interesting customers as they provide the best multiplication factor for developed solutions in contrast to specialized single solutions.

References

[1] Smirnov, A., and N. Shilov. "Context-Aware Smart Sustainable Factories: Technological Framework." Sustainable Manufacturing. Springer Berlin Heidelberg, 2012. 151-156.

[2] Emmanouilidis, Christos, and Petros Pistofidis. "Machinery self-awareness with wireless sensor networks: a means to sustainable operation." Proceedings of the 2nd workshop on maintenance for sustainable manufacturing. 2010.

[3] Kulic D., Croft E. (2004) Safe Planning for HumanεRobot Interaction. In: Proceedings of the IEEE International Conference on Robotics and Automation. New Orleans, LA, USA: pp. 1882ε1887.

[4] R. D. Schraft, M. Hägele, and A. Breckweg, "Man and robot without separating systems," In: World of Automation and Metalworking. Frankfurt/M.: VDMA Verlag, 2006, p. 4-5.

[5] J. Krüger, T. K. Lien, and A. Verl, "Cooperation of human and machines in assembly lines," In: CIRP Annals Manufacturing Technology. 58 (2009), No. 2, p. 628-646.

[6] Ferscha, A., Farrahi, K., Hoven, J., Hales, D., Nowak, A., Lukowicz, P., et al. (2012). Socioinspired ICT. The European Physical Journal Special Topics, 214(1), 401-434.

[7] Gil Press, Internet of Things By The Numbers: Market Estimates And Forecasts, http://www.forbes.com/sites/gilpress/2014/08/22/internet-of-things-by-the-numbers-market-estimates-and-forecasts/ [6] P. Lukowicz, A. Pentland and A. Ferscha: "From Context Awareness to Socially Aware Computing", IEEE Pervasive Computing, Vol. 11, No. 1, pp. 32–41, 2012.

[8] Spark, Nora Young, CBC, Attentive Interfaces with Roel Vertegaal (Full interview), http://www.cbc.ca/player/Radio/Spark/ID/2241132719/

[9] Saha, Debashis, and Amitava Mukherjee. "Pervasive computing: a paradigm for the 21st century." Computer 36.3 (2003): 25-31

[10] Satyanarayanan, Mahadev. "Pervasive computing: Vision and challenges."Personal Communications, IEEE 8.4 (2001): 10-17.

[11] A. Ferscha: Implicit Interaction, This Pervasive Day: The Potential and Perils of Pervasive Computing, Editors: Jeremy Pitt, Imperial College Press, pp. 17-36, ISBN: 978-1848167483, April 2012.

[12] Dey, A. K. (2001). Understanding and using context. Personal and ubiquitous computing, 5(1), 4-7.

[13] Lukowicz, P., & Ferscha, A. (2011). From context awareness to socially aware computing. IEEE pervasive computing, (1), 32-41.

[14] Stipancic, Tomislav, Bojan Jerbic, and Petar Curkovic. "Context-Aware System Applied in Industrial Assembly Environment." International Journal of Advanced Robotic Systems, Antonio Visioli (Ed.) 9 (2012).

[15] M. St. John, D. A. Kobus, J. G. Morrison, and D. Schmorrow, "Overview of the DARPA augmented cognition technical integration experiment", International Journal of Human-Computer Interaction, vol. 17, no. 2, pp. 131–149, 2004.

[16] D. Schmorrow and A. A. Kruse, "DARPA's augmented cognition program-tomorrow's human com- puter interaction from vision to reality: building cognitively aware computational systems", in Pro- ceedings of the IEEE Conference on Human Factors and Power Plants, 2002, pp. 7–1

[17] D. C. Engelbart, "Toward augmenting the human intellect and boosting our collective IQ", Com- munications of the ACM, vol. 38, no. 8, pp. 30–32, 1995.

[18] D. C. Engelbart and W. K. English, "A research center for augmenting human intellect", in Pro- ceedings of the Joint Computer Conference, 1968, pp. 395–410.

[19] A. Schmidt, "Implicit human computer interaction through context", Personal Technologies, vol. 4, no. 2-3, pp. 191–199, 2000.

[20] C. North, "Toward measuring visualization insight", IEEE Computer Graphics and Applications, vol. 26, no. 3, pp. 6–9, 2006.

[21] Tsotsos, John K. and Rothenstein Albert, Computational Models of Attention, http://www.scholarpedia.org/article/Computational_models_of_visual_attention

[22] C. D. Wickens. Processing resources in attention, pages 63–102. Number 3. Aca-demic Press, 1984.

[23] L. Itti and P. Baldi. Bayesian surprise attracts human attention. Vision Research, 49(10):1295–1306, 2009.

[24] Cisco Systems, Industrial Smart Solutions: Connecting the Factory to the Enterprise, Cisco Manufacturing White Paper, http://www.cisco.com/web/TH/tomorrow-starts-here/files/white_paper.pdf

[25] Corrales Ramón, Juan Antonio, et al. "Cooperative tasks between humans and robots in industrial environments." (2012).

Competencies

The OPPORTUNITY (IPC, FP7 ICT 2007-C, 2009 - 2012) project employed mobile sensor platforms to detect and analyze the activities of people, respectively their context. OPPORTUNITY addressed the research question of how heterogeneous, dynamically varying sensor platforms can be used to extract human activities from raw physical data streams via pattern classification and machine learning methods. The developed real-time-able framework can be evaluated as breakthrough in context recognition as it revises the traditional bottom-up of such systems into a top-down goal-oriented approach.

In the SAPERE (IPC, FP7 ICT call 5, 2010-2014) project, IPC has conducted research on the development of a highly-innovative theoretical and practical framework for the decentralized deployment of self-aware and adaptive services. The framework is grounded on a foundational re-thinking of current service models and of associated infrastructures and algorithms. In particular, drawing inspiration from natural ecosystems, the project demonstrates the possibility of modelling and deploying services as autonomous individuals in an ecosystem of other services and pervasive devices, and of enforcing self-awareness and autonomic behaviors as inherent properties of the ecosystem.

In the DISPLAYS (IPC, PCA, 2008 - 2011) project, a national project in the first RSA calls, public interactive display systems were developed. The result, the so called Smart Light is a multi-sensor, interactive HW-platform which has been advanced to market maturity and found application in diverse installations. These developments are currently carried on in the running FFG-founded project 360Light (IPC, PCA, FFG Nr. 848430, 2013-2015). In the scope of these projects, fundamental research in the fields of behavior analysis, attention estimation as well as implicit and explicit interaction has been carried out.

Recently, in the exploratory project Raising Attention (IPC, PCA, FFG Pr.Nr.: 840219, 2013- 2014, Project-Homepage) an academic and industrial mobilization of research in the field of Attention-Sensitive ICT has been initiated by the proposing research institutions. The result of the research activities is an Attentive ICT Whitebook including a potential analysis and a research roadmap in this evolving field of research.

Synergetic effects are expected from HC2 (IPC, FP7 ICT Call-5, FET proactive, Goal 8.4: Human Computer Confluence), a research program, focused on the symbiotic relation between human and IT with the goal of radically new levels of comprehension for IT systems. Beyond, the IPC held a workshop at the annual Ubicomp conference 2014 “The Superorganism of Massive Collective Wearables”, directed at transferring existing loads of wearable sensor systems into a super organism of socially-interactive assistance devices.

Proponent

Univ.-Prof. Mag. Dr. Alois Ferscha
Institute of Pervasive Computing

ferscha@pervasive.jku.at
www.pervasive.jku.at

The Institute of Pervasive Computing runs outstanding, state of the art laboratory equipment and experimental infrastructures, e.g. the Sensor Lab (Geolocation Sensors, Accelerometers, Gyroscopes, Position/LocationTrackers, Ultrasonic Sensors, Depth/Thermal Imaging, Pressure Sensors, MEMS, Bio-Signal Sensors, etc.), the Display Systems Lab (HDTV DLPs, Wearable Displays, Eye Trackers, Multiscreen HD LEDs, Tactor/Olfactory Displays, SmartWatches, etc.), and the 360 Lab (360 Video Sensors, Capturing, ProcessPipeline Tools, 360 broadcasting technology).

Keywords

Man-Machine Interaction, Aware and Assistive Systems, Computational Perception, Machine Learning, Embedded Intelligence, Wearable Computing

Visual Data Analytics

"Visual analytics is an emerging and fast-developing field that combines the strengths of graphical visualization with the power of analytical reasoning."

Marc Streit

Focus Line 4:

Mastering Complexity in Production and Communication Systems

Coordinator:

Assist.-Prof. DI Dr. Marc Streit Bakk.
Institut of Computer Graphics

marc.streit@jku.at
http://www.jku.at/cg

Research Focus

- Big Data Analysis
- Visualization of Complex, Heterogeneous Data
- Recommender and Guidance Systems
- Data Mining & Knowledge Extraction

Vision

Today, many algorithmic and mathematical solutions exist for analyzing large datasets such as biomolecular data or complex software source code. Gaining new insights from such data requires the ability to specify what we are looking for, from clusters of patients exhibiting similar gene expression to bugs in software systems. But what if we do not know what we expect to find?

Consider an example. A still unsolved problem is identifying the genomic alterations and processes that lead to particular cancer subtypes. Because biologists lack sufficient understanding, they are not able to formulate algorithms that analyze biomolecular data properly.

Visual analytics is an emerging and fast-developing field that combines the strengths of graphical visualization with the power of analytical reasoning. It supports discovering new and unknown insights by finding relations, patterns, trends, or outliers in potentially large and complex data. Because human analysts' unique sense-making skills are tightly coupled with interactive visualization techniques, visual analytics can lead to discoveries that neither a computer nor a human could make alone. Pairing both in an efficient way is the key to future analysis—and discovery [1].

As a pre-condition for Visual Analytics, data has to be provided in a proper form and functionalities have to be available that support processing the data before it is ready to be visualized, for instance, clustering, data integration, data and knowledge extraction. Even if there is a long history in these areas, there is a large demand for research and development, in particular when thinking of the increasing amounts of data available, the data quality, and the performance needs in terms of online visualization.

In the context of production research, we envision future systems that analyze and visualize a huge amount of integrated heterogeneous, eventually also unstructured, data with a performance and quality far beyond the current state-of-the-art. Production processes could be improved or adopted online based on decisions generated from much broader information bases. This will give practitioners in the field of production the means to extract new insights, understanding, and knowledge.

Approach

Visual data analytics is highly interdisciplinary and requires the interplay of a multitude of scientific fields, such **as visualization**, **data management**, **data mining** and **extraction**, **cognitive** and **perceptual sciences**, **interaction**, and many more.

Visualization: To address the needs arising from large and complex data, we develop novel visualization techniques that support analysts in making sense of the data. Clustering and Data Mining: Visual data analytics needs efficient data mining algorithms. To achieve the goal of analyzing complex data, we apply state-of-the-art approaches to the analysis problems at hand.

Information Integration: Typically, different data sources are hard to integrate. On all three levels (data storage, data model, data semantic) heterogeneity has to be overcome. In this area, we do active research in order to get a better quality of information integration. Modeling, gaining and using additional background knowledge is the way where we will continue our current research.

Information Extraction: Most of the data that is available nowadays is unstructured. Before being able to make meaningful analyses (e.g. [5]), information has to be extracted (e.g., what are the types and corresponding holder's age of cars involved in an accident described in an unstructured text). We plan to prolong our research in this field (e.g. [6]), in particular in 'web information extraction' and also adjust the methods to address open issues in production research.

Information Storage and Management: New trends in storing and managing huge amounts of data, such as highly distributed and parallel working information systems, will be adopted and applied for visual data analytics.

In order to be able to solve scientific problems in the context of data analysis, we are seeking local collaboration partners in Upper Austria and other Austrian states as well as international collaborators that can provide us with complex, large datasets and open domain problems.

Impact

Our work has impact in various scientific fields, including biology and medicine. As already mentioned in the vision section, our research and development can potentially impact production processes by providing a **new quality of decision support**. Additionally, analyzing production data, both visualizing them on a high abstraction level and drilling down to the data of one particular product, will be supported more efficiently compared to currently available approaches. Our research in the field of visual data analytics will allow industrial partners to gain **novel insights**, **understanding**, and **knowledge** from a **rapidly growing bulk of data**.

References

[1] M. Streit and O. Bimber: “Visual Analytics: Seeking the Unknown”, Computer, Vol. 46, No. 7, pp. 20-21, 2013.

[2] M. Streit, A. Lex, S. Gratzl, P. Partl, D. Schmalstieg, HP. Pfister, PJ. Park and N. Gehlenborg: “Guided Visual Exploration of Genomic Stratifications in Cancer”, Nature Methods, Vol. 11, pp. 884-885, 2014.

[3] Caleydo Visualization Framework, http://www.caleydo.org.

[4] LineUp Ranking Tool, http://lineup.caleydo.org.

[5] A. Kosorus, J. Hönigl and J. Küng: “Using R, WEKA and RapidMiner in Time Series Analysis of Sensor Data”, Proceedings of the International Workshop on Database and Expert Systems Applications (DEXA ‘11), pp. 306-310, IEEE, 2011.

[6] C. Feilmayr, K. Vojinovic, B. Pröll: “Designing a Multi-Dimensional Space for Hybrid Information Extraction”, Proceedings of the International Workshop on Database and Expert Systems Applications, pp. 121-125, IEEE, 2012.

Competencies

The competences of the Institute of Application Oriented Knowledge Processing include data mining and integration (Wolfram Wöß), web and knowledge extraction (Birgit Pröll), similarity queries and recommendations (Josef Küng), and process-aware information systems (Dagmar Auer, Josef Küng). At the Institute of Computer Graphics, Marc Streit and his group are working on topics related to visual analysis of heterogeneous data, guided data exploration, and big data visualization.

These competences are evident in all three domains of our academic portfolio of activities: **fundamental research**, **application-oriented research** in **cooperation with industrial partners**, as well as **teaching**.

In numerous research projects we aim at making sense of large & complex data, unstructured data, and even currently non-accessible data. All of our projects are carried out in a specific domain context where the developed methods can contribute to finding solutions to hard problems. In recent years, we worked on techniques that allow domain experts to identify and characterize tumor subtypes in large patient populations [2]. In close collaboration with **Harvard University** and **Graz University of Technology** we developed the Caleydo software [3], which has grown to a well-established framework for bio-molecular data analysis. In another research activity with Harvard, we developed a novel ranking technique to let people understand complex rankings [4].
In a further research project, which is carried out together with the **RISC Software GmbH** and funded by the Austrian Promotion Agency (FFG), we are developing new approaches for monitoring and administrating complex IT-infrastructures. In particular, we aim at automating the generation of a coherent and privacy-preserving overview of those infrastructures, allowing users to visually analyse the continuously increasing amount of data generated by the huge number of system components in complex infrastructures. However, although all newly developed methods are developed in a specific application context, they are generally applicable to other fields of science that deal with the same kind of data.

Also in the areas of data mining, information integration, information extraction, and information management numerous research projects of several types (FWF, EU-FP6. EU-FP7, FFG, direct collaborations with industry) have been finished successfully or are still ongoing. Example projects are: 'Setting up an information and knowledge base in the EU-FP7-Project CLAFIS – Crop, Livestock and Forests Integrated System for Intelligent Automation, Processing and Control', 'Hybrid Information Extraction', and 'Data Mining gestütztes Qualitätsmanagement bei BMW Motoren Steyr',
To guarantee an excellent training of our students, we offer numerous courses related to our main fields of research and also supervise student projects on all levels.

Proponents

Assist.-Prof. DI Dr. Marc Streit Bakk.
Institut of Computer Graphics

marc.streit@jku.at
http://www.jku.at/cg

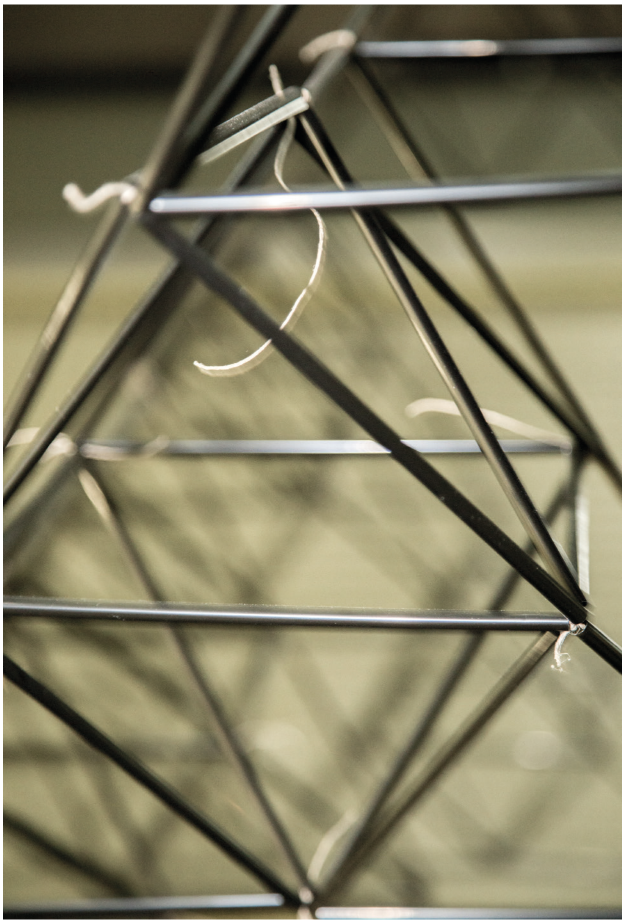
A.Univ.-Prof. DI Dr. Josef Küng
Institute of Application Oriented Knowledge

jkueng@faw.jku.at
http://www.faw.uni-linz.ac.at/faw/

Keywords

Information Visualization, Knowledge Discovery, Data Mining and Extraction, Big Data

Computational Mathematics in Industrial Applications



"The recent advances in Computational Mathematics open new perspectives for the simulation and optimization of industrial processes, in particular in production."

Bert Jüttler

Focus Line 4:

Mastering Complexity in Production and Communication Systems

Coordinator:

Univ.-Prof. Mag. Dr. Bert Jüttler
Institute of Applied Geometry

bert.juettler@jku.at
http://www.ag.jku.at/

Research Focus

- Simulation and Optimization of Industrial Processes based on Mathematical Modeling
- Competencies include Medical Imaging, Signal Processing, Parameter Identification and Optimization, Optimal Design, Computational Kinematics, Computer-Aided Design, Fault Detection
- Supported by On-going Basic Research on Numerical Analysis, Symbolic Computation, Computational Geometry and Related Fields
- Research in Symbolic Computation (Algebraic Elimination Theory, Groebner Bases, etc.)

Vision

The recent advances in **Computational Mathematics** open new perspectives for the simulation and optimization of industrial processes, in particular in production. The department of mathematics of JKU possesses a strong expertise in theoretical and application-oriented research and plays a leading role within Austria. This white-book statement focuses on the contributions of several mathematical institutes to Focus Line 4: Mastering Complexity in Production.

The **Industrial Mathematics Institute** aims at the **transfer of modern mathematical methods to industrial partners**. That includes the development of new methods for specific industrial problems as well as the adaption of known methods to the industrial problems at hand. To this end, the Industrial Mathematics Institute works in close cooperation with the Transfer Group of the **Johann Radon Institute for Computational and Applied Mathematics** (RICAM) and the company **MathConsult GmbH**.

The **Institute of Applied Geometry** organizes its research activities around theoretical and practical questions that originate in the interplay between **Computer Aided Design**, **Computational Geometry**, and **Numerical Simulation**. Its vision is to create a unified methodology for the geometric representation of products and processes that allows to break down the barriers that currently separate these different mathematical technologies. This will potentially lead to huge benefits not only for **product life-cycle management** from cradle to grave, but also for the simulation and optimization of production processes.

The **Institute of Knowledge-Based Mathematical Systems** (FLLL) has strong experience in intelligent data and signal processing for optical fault detection, quality control, data mining and knowledge-based modeling, as well as in prediction in and control of complex systems. Our understanding of quality control in industry 4.0 is triggered by future production processes which are integrated over different sites, monitor the state of each production step, give feedback along the complete manufacturing line, and automatically adapt to product variants and process drifts. The **manufactured products** are “**smart**” in the sense that they will keep data about the conditions under which they were manufactured, continue to monitor their state after leaving production, and actively trigger actions if their state gets out of specification. To ensure quality control under such circumstances intelligent methods for handling and aggregating data, in particular for extracting meaning and interpretable information from the available data is needed. Our vision is that knowledge-based methods will significantly improve complex industrial processes and the quality of products.

The **Institute of Computational Mathematics** focuses on the numerical solution of partial differential equations (PDEs) and optimization problems. In particular, we develop fast and robust methods for optimal control, topology optimization and optimal design problems. Beside classical discretization techniques like the Finite and Boundary Element Methods, we investigate new nonstandard discretization techniques for PDEs like fully coupled space-time discretization techniques and **Isogeometric Analysis**. Fast, robust and efficient (parallel) solvers for large-scale systems of algebraic equations arising from the discretization of PDEs are a traditional research topic of the institute. PDE models and optimization problems with PDE constraints arise in many industrial applications like applications connected with **solid and fluid mechanical models** or models from **electrodynamics** or models where different physical fields are coupled.

The activities of both the **Research Institute for Symbolic Computation** (RISC) institute and the **RISC Software company** cover a wide range of topics related to the use of symbolic computation, which includes research on **robot kinematics**. In particular we perform research in the field of inverse kinematics, i.e., the question of how the joints of a given robot have to be arranged so as to reach a particular goal. Various methods in algebraic elimination theory, in particular Groebner bases, play an important role.

Approach

The on-going work of the mathematical institutes on **Computational Mathematics in Industrial Applications** is characterized by the **interaction of theoretical and application-oriented research**. The research on theoretical questions provides a strong foundation and allows to obtain mathematical guarantees for the algorithms and computational techniques that are used to address the challenging problems arising in applications.

The research at the **Industrial Mathematics Institute** is devoted to the **mathematical modeling of industrial processes**, to the development of numerical simulation software and of methods for parameter identification in industrial processes. It also provides methods for the **optimization** of industrial processes as well as for optimal design, and for the **analysis of data** / **images**. The mathematical technology takes the form of dedicated software packages for customers based on developed methods.

The key expertise of the Institute of Applied Geometry is in the field of **Geometric Computing**, in particular in **Computer Aided Geometric Design** / **Geometric Modeling** and **Computational Geometry**. Based on powerful geometric algorithms and representations, the research explores applications to real-world industrial problems, which have ranged from the simulation of the dip-coating process of entire car bodies [1] to the numerical simulation of hydroelectric turbines and aircraft engines. The underlying mathematical technology of **spline curves and surfaces**, which is well established and has become an industrial ISO standard since the 1980s, is currently being extended into several directions. These extensions are driven by the need to provide local adaptivity, in particular in the context of new applications in numerical simulations [2]. The current algorithmic research results have materialized as an an OpenSource software library containing state-of-the-art adaptive technology.

The experience at the **Institute of Knowledge-Based Mathematical Systems** is that knowledge-based models and data-based models, defined "as any form of mathematical models which are fully designed, extracted or learned from data" [4], have often proven to be more suitable than traditional first principle models. The design of **learning algorithms** which are interpretable as well as sufficiently accurate and robust is a hot topic of current research [4]. Production environments often are non-stationary in the sense that manufacturing conditions may vary within specified boundaries, or even drift "out of spec". **Evolving learning techniques** [4] are one way to deal with such variations. Large and complex systems collect different types of data from many different sources which can be incomplete, inconsistent or even contradicting. Research into **aggregation** functions [3] leads to more reliable combinations of such data as a basis for final decisions. When a quality inspection system is parameterized for one specific product, the introduction of another product variant often invalidates this parameterization. Methods of **transfer learning** address this problem by facilitating the reuse of once learned models for similar tasks.

The numerical simulation of PDEs are classically based on **Finite Element Discretizations**. Smart and nonstandard Finite Element Techniques are still a hot topic in teaching and research, see [5]. Fast and robust solvers and their efficient implementation on parallel computers of different architectures have became more and more important due to the availability of such parallel computers. The institute has contributed to this topic in many publication in international journals, see also the tutorial [6] and the recent monograph [7].

A characterizing feature of RISC and the RISC Software GmbH is its specific combination of scientific know-how in mathematics (e.g. numeric and **symbolic computation**, computational geometry) and computer science (e.g. parallel computing technologies) and its ability to develop effective and sustainable software solutions for complex and challenging industrial problems. For many solutions that have been delivered over the past fifteen years a detailed understanding of the underlying mathematical algorithms as well as a distinguished expertise in latest software technologies have been crucial for the success.

In the area of industrial applications RISC Software GmbH focuses on the two topics **Computational Engineering** and **Manufacturing Processes**. The first one addresses the steadily raising importance of accurate and trustworthy software simulations for engineering sciences and virtual prototypes in product design. The second field of activities focuses on the development of high-quality simulations for machining processes and of efficient planning and programming tools. In order to achieve the defined performance goals or intended benefits quite often individually implemented algorithms making use of latest research results or newest hardware advancements are required.

Together with researchers from the University of Innsbruck and the Johann Radon Institut in Linz, RISC explores algebraic techniques for the construction and the analysis of **mechanical linkages**. The most important techniques are the Factorization Method for Motion Polynomials – based on dual quaternions -- and Bond Theory. These methods have been successfully applied to solve various previously open problems in theoretical kinematics, to find previously unknown families of linkages with particular properties, to simplify proofs for existing results, and to interpolate linkages that generate desired motions. These recent mathematical result have a strong potential for real-world applications.

Impact

Mathematical modeling, simulation and parameter identification has a significant impact on industry:

Reduction of test runs: Accurate mathematical simulation methods give a valid representation of a real life industrial system. Thus, the systems can be tested with different parameter configurations and setting, which significantly reduces the necessary tests runs on a "real" system, which leads to a significant reduction of costs.
Parameter Identification and Optimization: Based on a valid mathematical model and a simulation of an industrial system, mathematical methods can be used to find optimal configurations of the parameters of the system, which may lead, e.g., to reduced operating costs or reduced energy consumption of a system.

System Monitoring: For many industrial processes, the constant monitoring of system parameters is necessary for an efficient production process. Often, those parameters are not directly accessible but have to be extracted from indirect measurements, which requires methods from signal processing, imaging and parameter identification methods.

Model identification and process analysis for the optimized control of production processes. Development of mathematical methods in the field of symbolic and numerical computer algebra to model the behaviour of production without restrictive a-priori assumptions about the model. The theory of Groebner Bases is used, since it allows the structural capturing of non-linear relations in models.

The seamless integration of geometric modeling (Computer-Aided Design) and **numerical simulation** (e.g. using Isogeometric Analysis) opens new perspectives for the simultaneous optimization of design and production, thus for the optimization of costs and energy consumption in industrial processes.

A unified framework, which incorporates powerful algorithms from **Computational Geometry** up to **Computational Engineering**, supports product life-cycle management "from cradle to grave". This is especially important for complex (and often unique) products which are of ETO (engineering to order nature).

Research on knowledge-based systems (interpretable learning methods, evolving learning techniques, transfer learning) will result in a better understanding of machine learning and data-driven modelling techniques, provide a basis for further human-machine interaction research, and enable flexible (e.g. lot-size 1) and adaptive production processes with high process and product quality. This flexibility allows for shorter time-to-market cycles without compromising quality. "Smart" components which monitor their current state enable early detection of out-of-spec conditions, and hence increased reliability.

References

[1] B. Strodthoff, M. Schifko and B. Jüttler: "Horizontal Decomposition of Triangulated Solids for the Simulation of Dip-coating Processes", Computer-Aided Design, Vol. 43, 1891-1901, 2011.

[2] G. Kiss et al: "Adaptive CAD model (re-)construction with THB–splines", Graphical Models, conditionally accepted, 2014.

[3] M. Grabisch, J.-L. Marichal and R. Mesiar: "E. Pap, Aggregation Functions", Cambridge University Press, 2009.

[4] E. Lughofer: "Evolving Fuzzy Systems: Methodologies, Advanced Concepts and Applications", Springer, 2011.

[5] M. Jung and U. Langer: "Methode der finiten Elemente für Ingenieure: Eine Einführung in die numerischen Grundlagen und Computer Simulation", Wiesbaden: Springer-Vieweg, 2013.

[6] C.C. Douglas, G. Haase und U. Langer: "A Tutorial on Elliptic PDE Solvers and Their Parallelization", SIAM, Philadelphia, 2003.

[7] C. Pechstein: "Finite and Boundary Element Tearing and Interconnecting Solvers for Multiscale Problems", Heidelberg: Springer, 2013.

Competencies

In recent years, the Industrial Mathematics Institute has worked on the following projects with industrial partners: With Carl Zeiss Oberkochen, we have developed mathematical methods for the **optimal design of thin films** for optical system. With our Partner Teufelberger, we have developed signal processing methods for **identifying parameters** that determine the **quality of a produced rope**. With Bachmann Monitoring, we develop methods that identify parameter that characterize the state of a **wind power plant**. In particular, we identify unbalances in the rotating system that lead to an early wear out of the wind power plant. Adaptive Optics is used for image improvement for imaging systems that suffer from image degradation due to turbulences in, e.g., the atmosphere. With our partners European Southern Observatory and Microgate GmbH we develop methods that guarantee an **image correction with Adaptive Optics Systems** of Extremely Large Telescopes in real-time.
The **Institute of Applied Geometry** is involved in a large number of projects for basic research and for application-oriented research. Currently it coordinates an Austrian NFN (National Research Network, funded by the Austrian Science Fund - FWF) on Geometry + Simulation, which is dedicated specifically to improving the interaction between Geometric Modeling / Computer-Aided Design and Numerical simulation. The mathematical technology developed in the frame of this project is exposed to real-world applications in the frame of several European projects. Here we mention the EC project EXAMPLE, which explores advances techniques for the design and simulation of the air passage for aircraft engines (in cooperation with MTU Aero Engines/Munich). In another EC project entitled TERRIFIC, the institute cooperates with ECS Magna Powertrain on questions related to CAD data management for large assemblies in the automotive industry and the simulation of dip painting processes to obtain optimal results and reducing product development time.
The **Institute of Knowledge-Based Mathematical Systems** combines activities in basic research and application-oriented research in the fields of fuzzy logic and control, aggregation functions and decision making, interpretable and evolving learning methods, and machine learning. These methods are used in our joint projects with the COMET K-Center “Linz Center of Mechatronics” (LCM) and “Software Competence Center Hagenberg” (SCCH) as well as within the K-Projects “Process Analytical Chemistry”’ (PAC, coordinator RECENDT GmbH) and “Improving the usability of machine learning in industrial inspection systems” (UseML, coordinator PROFACTOR GmbH).
The Institute of Computational Mathematics participates in the Austrian National Research Network on Geometry + Simulation where we mainly cooperate with the Institute of Applied Geometry and the Johann Radon Institute of Computational and Applied Mathematics of the Austrian Academy of Sciences on Isogeometric Analysis of PDE models and on the software project G+SMO. In the Doctoral Programme “Computational Mathematics”, we focus on optimization problems with PDE constraints.

Proponents

Univ.-Prof. Mag. Dr. Bert Jüttler
Institute of Applied Geometry

bert.juettler@jku.at
http://www.ag.jku.at/

Univ.-Prof. Dr. Erich Klement
Department of Knowledge-Based
Mathematical Systems

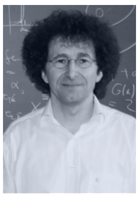
ep.klement@jku.at
http://www.flll.jku.at/

O.Univ.-Prof. DI Dr. Ulrich Langer
Institute of Computational Mathematics

ulrich.langer@jku.at
http://www.numa.uni-linz.ac.at/

Univ.-Prof. Dr. Peter Paule
Research Institute of Symbolic Computation

peter.paule@jku.at
http://www.risc.jku.at/



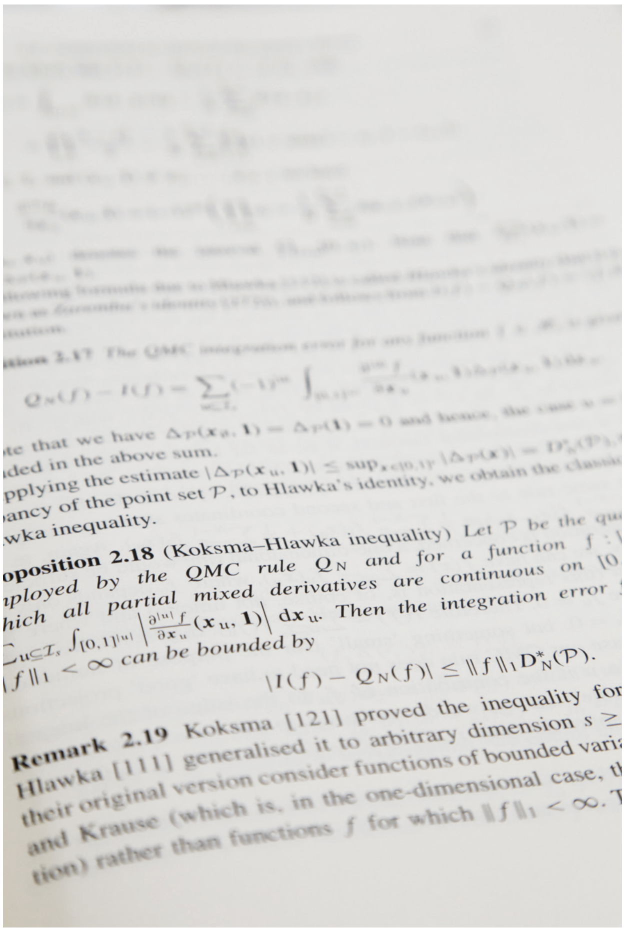
Univ.-Prof. Dr. Ronny Ramlau
Institute of Industrial Mathematics

ronny.ramlau@jku.at
http://www.indmath.uni-linz.ac.at/

Keywords

Simulation and Optimization of Industrial Processes, Mathematical Modeling, Medical Imaging, Signal Processing, Parameter Identification and Optimization, Optimal Design, Computational Kinematics, Fault Detection, Numerical Computation, Symbolic Computation, Computer-Aided Design, Computational Geometry

Mathematical Simulation and Financial Mathematics



"Suitable and carefully chosen and operated quasi-Monte Carlo methods can considerably increase the quality of the simulation results in applications and the speed in obtaining these results, which is of special importance."

Gerhard Larcher

Focus Line 4:

Mastering Complexity in Production and Communication Systems

Coordinator:

Univ.-Prof. Mag. Dr. Gerhard Larcher
Institute of Financial Mathematics

gerhard.larcher@jku.at
http://www.finanz.jku.at/

Research Focus

- Development of Highly Sophisticated Simulation Techniques
- Suitable Application of Simulation Methods in Fnance, Physics, Biology, Medicine, etc.
- Generation of High-Dimensional Well-Distributed Simulation Point Sets
- Decreasing the Complexity of Simulation Problems

Vision

The Institute of Financial Mathematics specializes in the generation and analysis of highly efficient mathematical simulation techniques and their application in different fields. The researchers at the institute are especially interested in applications from quantitative finance, like derivative pricing, risk management or in the analysis of trading strategies. But also applications in many other fields, like transport problems or problems originating from medicine and biology, are within the range of their interest.

The most well-known and most widely used mathematical simulation techniques are the so-called Monte Carlo-methods. **Quasi-Monte Carlo-methods** are an essential refinement of pure Monte Carlo-methods. The research groups at the Institute of Financial Mathematics at the JKU belong to the worldwide leading research groups on the topic of quasi-Monte Carlo methods. This assertion is supported by the following fact:

In December 2013 the FWF (the Austrian science fund) has granted a special research area (**SFB**) on the topic **"Quasi-Monte Carlo Methods: Theory and Applications"**. This SFB—which is intended for two four-year periods and which has started work in February 2014—is coordinated by Gerhard Larcher (speaker) and Friedrich Pillichshammer (co-speaker), both from the Johannes Kepler University Linz, and it connects ten research projects, led by Michael Drmota (TU Vienna), Peter Grabner and Robert Tichy (both TU Graz), Peter Hellekalek (Paris Lodron University Salzburg), Roswitha Hofer, Peter Kritzer, Gerhard Larcher, Gunther Leobacher, Friedrich Pil-lichshammer (all Johannes Kepler University Linz), and by Arne Winterhof (RICAM, OAW), respectively. The SFB funds make it possible to finance about 20 new Postdoc and PhD positions in research on the theory and the applications of quasi-Monte Carlo methods.

The work in this research project will be accompanied and monitored by an international Advisory Board of highly renowned experts in quasi-Monte Carlo (QMC) methods. The chair of the Advisory Board is Harald Niederreiter, who is a central figure in the field of QMC methods. In his research, he has frequently cooperated with the project leaders for many years, and he will thus play a central role in this SFB.

There is a variety of "big open problems" in QMC, problems partly arising from theory, partly arising from applications. **It is the aim of this SFB** to efficiently exchange the skills of the participating research groups, to analyze the new modern techniques in QMC and integrate them into the joint work, to develop powerful new methods and so to contribute in an essential way to solutions of the most challenging problems in the field. Further it will **create a Center of Excellence for the theory and the application of QMC-methods to be visible worldwide**.

Approach

By "quasi-Monte Carlo methods" we understand all methods in which most carefully chosen quasi-random-point sets are used to carry out simulations in the framework of sophisticated and highly developed modeling environments, for obtaining quantitative information in different branches of applications.

The study and development of QMC methods therefore requires

- the generation, investigation, and analysis of distribution properties of finite or infinite sequences in all kinds of regions
- the development, investigation, and analysis of suitable theoretical models on which the applications of the QMC methods are based, and in particular the derivation of error bounds for QMC methods in these models
- the efficient implementation of the theoretical models and of the algorithms for the generation of the (sometimes very large and high-dimensional) quasi-random point sets, and the provision of sophisticated software
- the concrete application of the QMC methods in different areas, the discussion of the implications and of the performance of the applied QMC methods.

Consequently, many different branches of mathematics are involved in the comprehensive investigation and development of QMC methods, most notably number theory, discrete mathematics, combinatorics, harmonic analysis, functional analysis, stochastics, complexity theory, theory of algorithms, and numerical analysis. Furthermore, profound knowledge of the branches of applications in which the QMC methods are intended to be used is necessary.

The theory and application of QMC methods is a modern and extremely lively branch of mathematics. This is demonstrated by an enormous output of research papers on this topic over the last decades, and by the great and growing success of the series of the biannual international conferences on "Monte Carlo and Quasi-Monte Carlo Methods in Scientific Computing" (MCQMC), which started in 1994 in Las Vegas and was most recently held in Sydney in 2012 and in Leuven (Belgium) 2014.

The Austrian research groups initiating this SFB play leading roles in the development of QMC methods.

It is the aim of this SFB to intensify the cooperation both between these research groups and with their international partners, to promote new directions and new developments within the theory of QMC methods and their applications, and to train a new generation of highly talented young researchers to carry out research work in the field of QMC methods.

Impact

We are at the center of a worldwide network of research groups applying (quasi-) Monte Carlo methods in all possible fields of applications. So besides our central competences (foundations of quasi-Monte Carlo methods, application of quasi-Monte Carlo methods in quantitative finance) we are in contact with the top-specialists in various fields of applications and we can provide that contact to others.

In particular, we are organizing one of the main international events in the field of Monte Carlo and quasi-Monte Carlo method: the MCM-conference (IMACS Seminar on Monte Carlo Methods) will take place at the JKU in Linz in June 2015.

Suitable and carefully chosen and operated quasi-Monte Carlo methods can considerably increase the quality of the simulation results in applications and the speed in obtaining these results, which is of special importance when we have to deal with very high-dimensional problems (as is the case in many applications from quantitative finance).

References

[1] L. Del Chicca, G. Larcher and M. Szölgyenyi: “Modeling and Performance of Certain Put-Write-Strategies”, The Journal of Alternative Investments, Vol. 15, No. 4, pp. 74-86, 2013.

[2] J. Dick and F. Pillichshammer: “Digital Nets and Sequences - Discrepancy Theory and Quasi-Monte Carlo Integration”, Cambridge University Press, 2010.

[3] P. Glasserman: “Monte Carlo Methods in Financial Engineering (Stochastic Modelling and Applied Probability)”, Springer 2003.

[4] G. Larcher and G. Leobacher: “Quasi-Monte Carlo and Monte Carlo methods and their applications in finance”, Surveys on Mathematics for Industry, Vol. 11, pp. 95-130, 2005.

[5] G. Leobacher: “A short introduction to quasi-Monte Carlo option pricing”, in: Uniform distribution and quasi-Monte Carlo methods - Discrepancy, integration and applications, de Gruyter, Berlin, 2014, to appear.

[6] G. Leobacher and F. Pillichshammer: “Introduction to Quasi-Monte Carlo Integration and Applications”, Birkhäuser, 2014.

Competencies

The basic competence of our research groups is the optimal design of the suitable mathematical simulation methods in various fields of applications. This basic competence is based on our continuous analysis and further development of the theoretical foundations of quasi-Monte Carlo methods.

Our special competences in the applications of our methods are in the field of quantitative finance and insurance. We have carried out many applied projects (consulting, expertises ...) in the fields of pricing of complex financial derivatives, in the design and the analysis of derivative financial trading strategies, or in quantitative risk management (especially estimating the risk of financial portfolios).

A quite new development in our research and in our applications in mathematical simulation theory was initiated recently by our research groups: We developed so-called hybrid simulation methods, which try to combine the benefits of pure Monte Caro-methods with the benefits of quasi-Monte Carlo-methods. It seems that for many applications this new type of simulation techniques should be very fruitful.

Proponent

Univ.-Prof. Mag. Dr. Gerhard Larcher
Institute of Financial Mathematics

gerhard.larcher@jku.at
http://www.finanz.jku.at/

Keywords

Monte Carlo Methods, Quasi-Monte Carlo-Methods, Applications in Mathematical Finance, Derivative Pricing, Risk Management, Analysis of Trading Strategies, Transport Problems, (quasi-) Monte Carlo-Methods in Medicine

Focus Line 5: Product Lifecycle Management and Product Ecosystems

FL5-01 **Sociological Research on Technology and the Industrial Sector**
Coordinator: Johann Bacher, Susanne Pernicka - Institute of Sociology - Department of Empirical Social Science Research

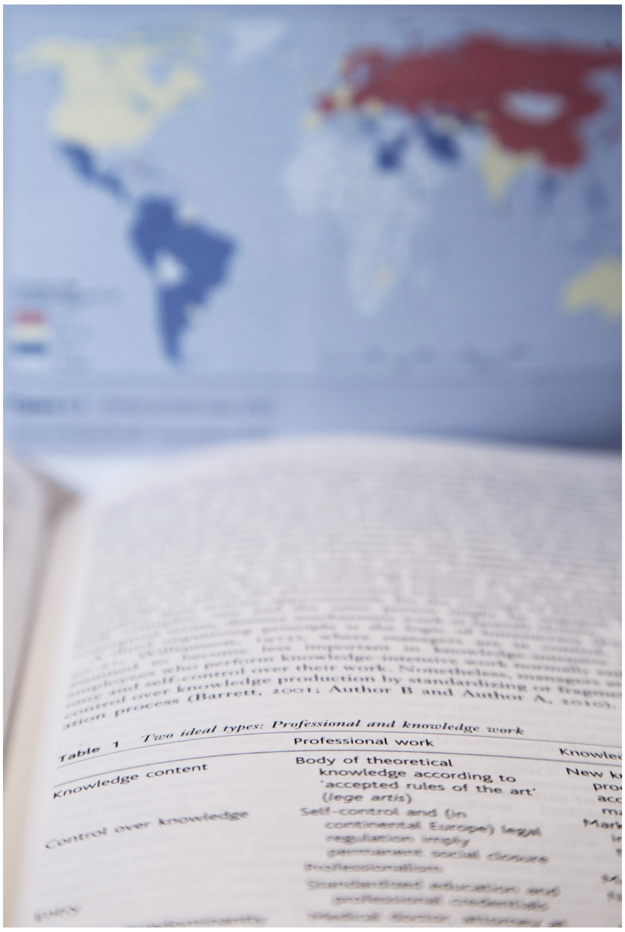
FL5-02
Sustainable Product and Process Design – Creating Acceptance
Coordinator: Johann Höller, Elisabeth Katzlinger - Department of Data Processing in Social Sciences, Economics and Business

FL5-03 **Corporate Governance as competitive advantage in Emerging Markets**
Coordinator: Helmut Pernsteiner - Department of Finance - Corporate Finance

FL5-04 **A Future Orientated Welfare Measure Combining Economics, Ecology and Happiness**
Coordinator: Friedrich Schneider - Department of Economics

FL5-05 **Dynamic Capabilities and Business Intelligence**
Coordinator: Christian Stary - Department of Business Informatics - Communications Engineering, Michael Schrefl - Department of Business Informatics - Data & Knowledge Engineering

Sociological Research on Technology and the Industrial Sector



"Interdisciplinary research within the social sciences and beyond, i.e. with natural and technical sciences is vital in order to understand the interrelationships between societal, environmental and technological challenges on the one hand and social sustainability on the other hand."

Johann Bacher

Focus Line 5:

Product Lifecycle Management and Product Ecosystems

Coordinator:

Univ.-Prof. Mag. Dr.Johann Bacher
Institute of Sociology -
Department of Empirical Social Science Research

johann.bacher@jku.at
http://www.jku.at/soz/content/e94921

Research Focus

- Causes and Consequences of Human Behaviour in Societal Fields
- Social Partnership Institutions at Enterprise, Regional, National and International Level, Innovation and Vocational Education and Training (VET)-Systems and Their Impact Upon Social Stratification, Solidarity and Democracy
- Interrelationships between Societal, Environmental and Technological Challenges
- Human Resource Management Work-Life-Balance

Vision

Sociological research deals with the **causes** and **consequences of human behaviour** in a wide variety of societal fields. The sociology of social structure, stratification and inequality as well as economic sociology are among the key sub-disciplines in sociology which adress the development of the economy and society and its impact upon social status, income distribution, solidarity and democracy. **Technological innovation** and **advances** in the industrial sector provide the basis for economic prosperity as well as for social cohesion. However, these outcomes do not evolve as natural phenomena. As has been demonstrated by the most recent economic and financial crisis, the performance of countries and sectors differ in relation to their societal institutions. Low unemployment rates, particularly among young people, negotiated working time reduction in the manufacturing sector, the success stories of all inclusive collective agreements and the apprenticeship system in Austria before and during the crisis are the outcomes of both, high value innovation and production systems as well as a strong tradition of social partnership between (organised) business and labour. This so called '**crisis corporatism**' has contributed to keep the unemployment rate low and to maintain a highly skilled workforce at their workplaces.

International comparative research on **Varieties of Capitalism** ([2], [3], [7]) distinguished between **liberal** (LMEs) and **coordinated market economies** (CMEs). Coordinated market economies, such as Austria, are characterised by their cooperative interrelationships between organised business, labour and state actors. Moreover, CMEs focus more on incremental innovation while LMEs specialise in radical innovation. To address future economic and social developments in a globalising world, the successful path of generating a highly skilled workforce, incremental innovations in manufacturing and a cooperative climate between (organised) labour and business should be maintained.

Against this background the vision statement proposes research on **Social Partnership** institutions at enterprise, regional, national and international level, innovation and Vocational Education and Training (VET)-systems and their impact upon social stratification, solidarity and democracy. Interdisciplinary research within the social sciences (sociology, business studies, economics, etc.) and beyond, i.e. with natural and technical sciences is vital in order to understand the interrelationships between societal, environmental and technological challenges on the one hand and social sustainability on the other hand.

Despite the above mentioned success stories of the Austrian corporative system, a declining interest of young people in technology and engineering ([5]) on the one side and low competencies at the end of compulsory school on the other side characterise the educational system in Austria ([1]). This development results in **missing labour force in the fields of industrial production**. Hence one future challenge is to increase the interest and the competences in technology and natural science in order to guarantee sufficient supply of qualified labour. The evaluation of and the attitudes towards technology in the society is one important barrier and will be studied in this project. Another important challenge is work-life-balance. The hypothesis can be stated that enterprises will only be successful in human resource management, especially in attracting female and highly qualified employees if they are able to offer a certain work-life-balance.

Approach

The **Department of Empirical Social Sciences Research** has a long tradition in survey research and statistical data analysis. Available data sources, like ESS (European Social Survey), TIMMS (Trends in International Mathematics and Science Study), PISA (Programme for International Student Assessment) and PIAAC (Programme for the International Assessment of Adult Competencies) will be re-analysed. PISA2006 and PISA2015 for example focus on competencies in and attitudes towards natural science and technology and enable to analyse and identify factors influencing positive interests, motives and competencies. Qualitative research on motivations of students in engineering and natural science will complement the data source of the analysis.

The **Department of Economic and Organisational Sociology** has a long tradition in research on Social Partnership institutions, collective bargaining and employee representation at enterprise (Works Council, European Works Council), sector and national level, VET Systems, social stratification and economic and industrial democracy. Over the last four years, the focus has been shifted to comprise actors, structures and processes within the economy and the society from an international comparative perspective. In contrast to efficiency oriented models of Institutional Economics that focus on the optimal allocation of scarce resources ([3], [8]), we take a more critical stance vis-à-vis institutions of market economies and see markets primarily as embedded in a capitalist social order that systematically produces inequality between labour and business ([4]). From this perspective issues such as income distribution and social integration are of utmost importance. Institutions are perceived as contested and contentious phenomena.
Within the above mentioned Varieties of Capitalism Framework, coordinated market economies are assumed to provide more equality than liberal market economies. This is due to a coordinated relationship between organized business and labour in CMEs. From an international comparative perspective the institutions of labour representation at enterprise level (Works Councils) and the two Chambers of Commerce (Wirtschaftskammer) and of Labour (Arbeiterkammer) with their compulsory membership provide a unique institutional resource that explains the relatively stable institutional configuration in Austria. Apart from industrial relations institutions, the Department of Economic and Organisational Sociology is involved in research on VET systems as well as intellectual property rights and their impact upon the distribution of income and institutions of co-determination and labour representation, such as trade unions. For our empirical investigations we employ a wide variety of research interest driven methodological

instruments, such as quantitative and qualitative methods of data collection and analysis, and within these expert interviews, focus group discussions, participant observation, survey research, etc.

Impact

The research conducted within the Institute of Sociology is expected to contribute to the **national and international scholarly discourse** on **Varieties of Capitalism**, **international competitiveness**, **social cohesion**, **social stratification** and **inequalities**, **economic** and **industrial democracy** as well as on attitudes towards technology, industry and natural sciences.

In terms of its societal impact, the Institute of Sociology provide regional, national and international business actors, experts and politicians in the fields of economic and social policy as well as in education with policy recommendations and information.

References

[1] M. Bruneforth, C. Weber and J. Bacher: “Chancengleichheit und garantiertes Bildungsminimum in Österreich”, in B. Herzog-Punzenberger (ed.), Nationaler Bildungsbericht Österreich 2012. Band 2, Graz: Leykam, pp. 189-229, 2012.

[2] D.W. Gingerich and P.A. Hall: “Varieties of capitalism and institutional complementaries in the macroeconomy. An empirical analysis”, MPIfG Discussion Paper 04/5. Cologne: Max Planck Institute for the Study of Societies, 2004.

[3] P. Hall and D. Soskice (eds.): “Varieties of capitalism: the institutional foundations of comparative advantage”, Oxford University Press, 2001.

[4] S. Pernicka and V. Glassner: “Transnational strategies of trade unions towards European wage policy. A neoinstitutional framework”. European Journal of Industrial Relations OnlineFirst, doi 10.1177/0959680113518232, 2014.

[5] P Potvin and A. Hasni: “Interest, motivation and attitude towards science and technology at K-12 levels: a systematic review of 12 years of educational research”, Studies in Science Education, Vol. 50, No.1, pp. 85-129, DOI: 10.1080/03057267.2014.881626, 2014.

[6] D. Tamesberger and J. Bacher: “NEET youth in Austria: a typology including socio-demography, labour market behaviour and permanence”, Journal of Youth Studies, OnlineFirst, do: 10.1080/13676261.2014.901492, 2014.

[7] K. Thelen: “Varieties of capitalism: trajectories of liberalization and the new politics of social solidarity”. Annual Review of Political Science, Vol. 15, pp. 137-159, 2012.

[8] O.E. Williamson: “The economics of organization: the transaction cost approach”. The American Journal of Sociology, Vol. 87, No. 3, pp. 548-577, 1981.

Competencies

The competencies of the Department of Empirical Social Sciences Research lie in the fields of survey research and statistical data analysis. For example, the Department has been involved in the different social reportings, like national educational report ("Nationaler Bildungsbericht"), youth report ("Jugendbericht") or family report ("Familienbericht").The Department has participated in international projects (e.g. TRANSEUROPE) and was engaged in many regional projects. Many projects have been done within an interdisciplinary research team using multi-method designs, like a mixture of quantitative and qualitative research methods. Publications in international journals are available, e.g. most recently [6].

The competencies of the Department of Economic and Organisational Sociology lie in a wide variety of expertise in the fields of Industrial Relations, European Sociology, Organisational Theory, Social Stratification Research and Employment Systems. The Department has been involved in a number of regional and international research projects. The most recent project is called "Horizontal Europeanization", a research unit funded by the German Research Foundation (Deutsche Forschungsgemeinschaft, DFG) from 2012-2015 (with a possible extension until 2018) that consists of seven renown university departments in sociology (for further information, please refer to http://www.horizontal-europeanization.eu/de). The focus is on processes of Europeanization in distinct empirical fields, such as higher education, social inequality, Asylum administrative practices and labour relations. The Department of Economic and Organisational Sociology is focused on labour relations in two sectors of the economy: Automobile industry and Health Care Organizations.

Proponents

Univ.-Prof. Mag. Dr. Johann Bacher
Institute of Sociology - Department of Empirical Social Science Research

johann.bacher@jku.at
http://www.jku.at/soz/content/e94921

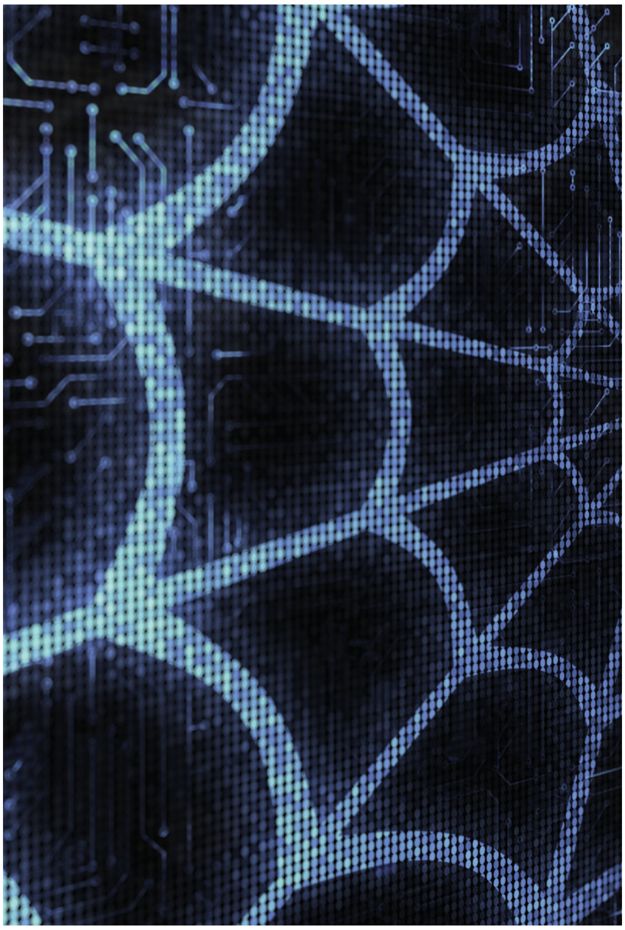
Univ.-Prof.in Dr.in Susanne Pernicka
Institute of Sociology - Department of Economic and Organisational Sociology

susanne.pernicka@jku.at
http://www.jku.at/soz/content/e94924

Keywords

Innovation, Human Capital, Social Cohesion, Social Partnership, Technology Acceptance, Vocational Education and Training Systems

Sustainable Product and Process Design – Creating Acceptance



“Smart technologies like ‘smart metering’ or the electronic health record can lead to privacy concerns and consequent resistance in the population, which can in the further consequence even prevent the successful application and usage of these products or services.“

Johann Höller

Focus Line 5:

Product Lifecycle Management and Product Ecosystems

Coordinator:

A.Univ.-Prof. Mag. DDr. Johann Höller
Department of Data Processing in Social Sciences, Economics and Business

johann.hoeller@jku.at
http://www.idv.uni-linz.ac.at/

Research Focus

- The Web as a Basis for the Digital Management Especially as a Driver for Business Model Innovation
- New Participation Models Using Customers Intelligence and Social Media to Improve Product Innovation Capabilities
- Optimizing Digital Management Decision Within the Legal Framework Including Copyright and Data Protection
- Digital Learning Environment in Higher Education and Corporate Contexts

Vision

Numerous examples show that disregard of the public's acceptance of industrial products and services has impeded their successful use. The history of nuclear power in Austria is an outstanding example: The almost completed nuclear power plant Zwentendorf was never brought on line because of a negative referendum.

Smart technologies like "smart metering" or the electronic health record can lead to privacy concerns and consequent resistance in the population, which can in the further consequence even prevent the successful application and usage of these products or services.
Nanomaterials, as used for example in cosmetics and cleaning agents, lead to negative environmental effects. The nanoparticles end up in the phreatic water or in the air and finally find their way into the food cycle, which leads to a demand for the abandonment or prohibition of these substances.

The rejection of genetic engineering in food shows how vigorously acceptance differs in various regions and cultures. Whilst genetic engineering in human medicine is mainly accepted in our cultural environment, it is not accepted when used by the food industry. Obviously, the application of the same technology receives different acceptance by the public.

Our vision is to avoid these errors without impeding industrial progress. The aim is to create methods for estimation and/or generation of acceptance towards industrial products. These methods should cover the broader range of tasks, which enterprises have to deal with in this context.

For companies it is essential to recruit employees, who can handle and interpret big data in different formats. As these data are becoming increasingly enriched by location-based information, it becomes more and more demanding to configure, analyze and interpret this kind of data for making appropriate decisions. On the other hand limiting the amount of data collected and monitoring the consumers perception helps to create and maintain acceptance. The obtaining or making available the appropriate skills therefor will be a key success factor in the implementation of Industry 4.0 strategies. We enable our master students of Web Sciences and Digital Business Management to fulfil these demands.

Approach

Industrial Management is an established science that is currently extended by digital media, particularly the **Internet** (**Digital Agenda**). Existing disciplines are broadened and additionally numerous new sub-disciplines arise, such as **e-marketing** or **e-procurement**, amongst others.

Corporate communications
The trend towards globalization leads to an increasing dependence on electronic media. This generates a new focus of corporate communications in the field of web communication, such as social media or various forms of e-participation. Research methods in this field are for example qualitative and quantitative methods of social media analysis, interaction and participation analysis as well as reception studies.

Business Model Innovation / Digital Business
The term Industry 4.0 includes the progressive change of value chains into value networks. On the one hand this creates potential for new business models and on the other hand it creates the need to rethink and optimize existing business models. In many cases this leads to an increased proportion of digital value-added components. Networking and division of labor also allow start-ups to gain a foothold in industry-related service areas. The research methodologies include the classic economic methods, especially case studies and action research.

Digital Education
More complex products and processes require a broadened knowledge among employees and customers. The acceptance of new products and processes also implies a basic level of knowledge. This creates a need for training, not only on the part of the employees but also on the part of potential customers and even the general public. This task is even more difficult to enforce when people are not involved directly. In this case, classic training methods are often not enough.

Suitable approaches in this area are e-learning and Action Research in addition to educational based methods. In order to get hold of the general public, game-based learning or gamification should be favored; however the combination of information and entertainment (infotainment) is discussed as promising, too.

Impact

Awareness of the need for the vision mentioned above should have been created. In the future the management of an industrial company cannot be limited to the development of a product or a service, but also has to consider the complex value network with all stakeholder interests. The main emphasis lies on the consumers' needs and their consequential behavior. Following these principles leads to more successful product development.

For companies that wish to act according to these principles, appropriate management models and tools will be developed and supplemented with collections of best-practice examples. As there is no thinkable "one-fits-all" solution, we provide solutions for the specific needs of companies or whole branches.

References

[1] E. Gauthier: "‚Green' food processing technologies: factors affecting consumers' acceptance", in: J.I. Boye and Y. Arcand (eds.), Green Technologies in Food Production and Processing, Springer US, pp. 615-641, 2012.

[2] J. Höller, R. Zlabinger and M. Pils: "Internet und Intranet - Herausforderung E-Business", Berlin: Springer, 2003.

[3] E. Katzlinger-Felhofer and M. Herzog: "Intercultural Collaborative Learning Scenarios in E-Business Education: Media Competencies for Virtual Workplaces", in T. Issa, P. Isaias and P. Kommers: "Multicultural Awareness and Technology in Higher Education: Global Perspectives, Hershey, PA: IGI Global, pp. 24-46, 2014.

[4] E. Katzlinger-Felhofer and J. Mittendorfer: "Entwicklung von Lernszenarien in mobilen Web 2.0 Anwendungen", Wireless Communication and Information, 2009.

[5] C. Meyer and J. Kerby: "Leadership in the Age of Transparency", Harvard Business Review, April 2010.

[6] J. Mittendorfer: "Kann man aus dem Web eine Wissenschaft machen?" ECOCOM 2013.

[7] M. Wolsink: "Wind Power: Basic Challenge Concerning Social Acceptance", in M. Kaltschmitt, N.J. Themelis, et al. (eds.), Renewable Energy Systems, pp. 1785 – 1821, 2013.

Competencies

The Institute of Data Processing in Social Sciences, Economics and Business carries out research and application in the field of digital business, corporate communication and digital education. The competencies of the institutes' staff cover a wide range of subjects from business informatics, business administration and business education to law. The focus of the projects covers interdisciplinary research such as the expansion of regional networking infrastructure ("Regional Networking in the Service of Environment, Energy and Economy - The Example of Austria's Waldviertel") or procurement management support systems for small and medium-sized companies. In cooperation with the government of Upper Austria, projects using geographic information were realized, like the "APP"er Austrian Award Winner "Geostar" which uses Open Data. The usage of social media for corporate communication in fields like e-marketing or crisis communication is in the focus of numerous research projects.

The institute is strongly involved in the development of curricula for new academic degree programs as far as forward-looking competencies in Industry 4.0 are concerned. Especially the degree programs Web Sciences and Digital Business Management prepare students for the needs of a globalized economy. On the other hand blended learning concepts are realized in university context, like for example MUSSS (Multimedia Study Services Social Sciences and Economic).

Proponents

A.Univ.-Prof. Mag. DDr. Johann Höller
Department of Data Processing in Social Sciences, Economics and Business

johann.hoeller@jku.at
http://www.idv.uni-linz.ac.at/

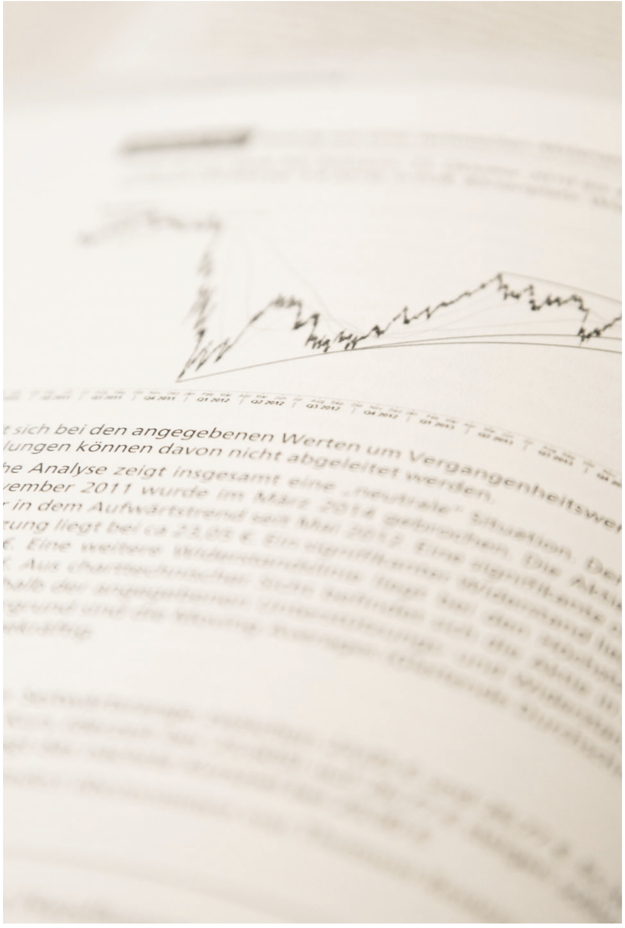
Assist.-Prof.[in] Mag.[a] Dr.[in]
Elisabeth Katzlinger-Felhofer
Department of Data Processing in Social Sciences, Economics and Business

elisabeth.katzlinger@jku.at
http://www.idv.uni-linz.ac.at/

Keywords

Business Model Innovation; Digital Business; E-Marketing; E-Procurement; Corporate Communication; Digital Education; Sustainability; Technological Acceptance

Corporate Governance as Competitive Advantage in Emerging Markets



"While there is no one formula for achieving success when entering markets, recent evidence suggests that good governance is a competitive advantage."

Helmut Pernsteiner

Focus Line 5:

Product Lifecycle Management and Product Ecosystems

Coordinator:

O.Univ.-Prof. Mag. Dr. Helmut Pernsteiner
Department of Finance - Corporate Finance

helmut.pernsteiner@jku.at
http://www.jku.at/ibfw

Research Focus

- Finance, Corporate Governance and Corporate Social Responsibility
- Financial Management of Family Firms
- Financial Management of Firms in Emerging Markets
- Mergers and Acquisitions

Vision

As the amount of global players entering emerging markets increases, industrial players in several sectors are exposed to more intense competition. Companies are looking for strategic partners in Emerging Markets to ensure their future growth. Management needs support to succeed in an increasingly complex and globalized economy and corporate governance can become an important differentiator. Corporate governance can be seen as a system which reduces the conflict of interest between the types of owners and managers and refers to a system of controls, regulations and incentives. The challenge lies in using corporate governance as a tool to add value and strengthen financial success. In the era of Corporate Governance, manufacturing companies have a unique opportunity to achieve a competitive advantage by using their successful governance in Emerging Markets as a sign of quality. There is a particular need to comply with a growing array of laws and regulatory codes in an international environment when entering new markets. Recent surveys demonstrate that Emerging Market CEOs are showing an increased interest in strong business ethics. Good and effective Corporate Governance can be used to highlight strategic opportunities and to build confidence in strategic partners and stakeholders in Emerging Markets. Some industrial firms have recognized that in these efforts there lies an opportunity and competitive advantage and therefore a chance to improve business performance.

Approach

While there is no one formula for achieving success when entering markets, recent evidence suggests that good governance is a competitive advantage. Effective governance, while not traditionally thought of as part of an international success development agenda, has come to be seen as an essential component of international market entry strategy.

The proposed research aims to shed light on which corporate governance indicators (including compliance and anticorruption mechanism) of industrial firms correlate with successful strategies (performance/value) of new Emerging Markets (China). An independent corporate governance index is assessed to measure governance efficiency along several dimensions. Empirical evidence by means of a sample of industrial companies will demonstrate which corporate governance mechanisms are associated with an outperformance related to their peers over time. This research focuses on the key success drivers attributable to governance in an international context.

(A developed Corporate Governance profile will be improved and validated through a variety of techniques.)

The empirical design includes interviews with operational managers from different industrial organizations. Furthermore, the impact of governance efficiency dimensions is linked to a variety of operating performance and value measures.

Impact

This research explores corporate governance policy as a strategic tool and competitiveness factor. It allows organizations to understand and rationalize their governance structure and controls in order to create a governance policy that builds mutual trust and enhances business performance when conducting business internationally.

The management of an industrial company can use the outcome of this research to improve and strengthen their governance process especially in an M&A/FDI context into Asian emerging markets.

A focus on corporate policy and internal controls allows the management to identify new opportunities to enhance business performance (increase profits) and add value in current and future business initiatives in emerging markets.

References

[1] T. Khanna, J. Kogan and K. Palepu: "Globalization and Similarities in Corporate Governance: A Cross Cultural Analysis", The Review of Economics and Statistics, Vol. 88, No. 1, pp. 69-90, 2006.

[2] R.K. Morck (ed.): "A History of Corporate Governance around the World", Chicago Press, 2005.

[3] H. Pernsteiner and H. Sumer (eds.): "Management in Emerging Markets", Wien: Linde, 2010.

[4] H. Pernsteiner and H. Sumer (eds.): "Finanzierung und Controlling in Emerging Markets", Wien: Linde, 2011.

[5] R. Rajan and L. Zingales: "Saving Capitalism from Capitalists", New York: Princeton University Press, 2003.

Proponent

O.Univ.-Prof. Mag. Dr. Helmut Pernsteiner
Department of Finance - Corporate Finance

helmut.pernsteiner@jku.at
http://www.jku.at/ibfw

Keywords

Corporate Governance, Compliance, Emerging Markets, Market Entry, M&A, FDI

A Future Orientated Welfare Measure Combining Economics, Ecology and Happiness

"The vision here is, to develop such a combined measure, using the disciplines of Economics, Ecology, Sociology and Psychology and to try in an interactive and interdisciplinary approach to come to a vision of a combined welfare measure."

Friedrich Schneider

Focus Line 5:

Product Lifecycle Management and Product Ecosystems

Coordinator:

O.Univ.-Prof. Mag.Dr. h.c. Friedrich Schneider
Department of Economics

friedrich.schneider@jku.at
www.econ.jku.at/schneider

Research Focus

- New Measure of GDP and Welfare
- Combination of Welfare and Luck
- Standardized New Measures of Economic Well-Being

Vision

The traditional measure of welfare is totally unsatisfactory. In Economics we count the total sum of all goods and services produced and normally use this as a welfare measurement in form of total Gross Domestic Product (GDP) in millions of currency units or of total GDP per capita in currency units. In the ecological sphere we count welfare measures as the ecological footprint or as the ecological burden measured in energy consumption or measured in material consumption. There is little interaction between the two welfare measures. Sometimes it is tried to combine them.

There is another research area, the Happiness research, where as a welfare measure "happiness" is used in such a respect that if someone is happy or if someone feels good, he/she has gained a high level of welfare. There are also other measures used considering the welfare of people, e.g. how much they earn and how much wealth they have, but all these measures are unsatisfactory.

Therefore, we urgently need to develop a scientific vision about a future welfare measure, in which at least Economics, Ecology and Happiness are combined, so that all three aspects are reflected in one measure. This would have the great advantage that if a country gets economically richer but ecologically poorer the welfare may be the same or even de-cline. Hence, it is a challenging task for researchers in Social Sciences to develop such a measure and to test, whether it is usable as a welfare approach and superior over the traditional ones. We urgently need such a welfare approach, because the partial measures today are totally misleading. The vision here is, to develop such a combined measure, using the disciplines of Economics, Ecology, Sociology and Psychology and to try in an interactive and interdisciplinary approach to come to a vision of a combined welfare measure.

Approach

The scientific approach to reach this goal is not easy to find. A first step would be a rigorous analysis of the concepts in the sub-disciplines Economics, Ecology, Sociology and Psychology (here especially happiness). Then, when this basic scientific work is done, in a next step and in an interactive process, using workshops and electronic communication, a combined approach should be developed between the researchers of these areas in an interdisciplinary way, in which the focus disciplines are combined. The goal here should be to use the Delphi method to suggest a total measure and to then distribute it among the colleagues, who can improve it until we finally reach a stadium in which such a measure is developed. How this will work? As this is a project where we have no concrete ex-ample, this is an open question and the first step should be to develop this type of Delphi method and then to develop this overall or total welfare concept.

Impact

The impact of such an overall concept, which contains the areas Economics, Ecology and Happiness, will be substantial if really accepted as overall welfare measure. As we do not have such a measure, it will be used for comparing the future development of countries all over the world. Moreover, it would be very helpful to have this measure in evaluating technological progress, economic progress and ecological progress, but also the single wellbeing of the individuals in countries and then to compare these levels of development with a single measure.

References

I am engaged in a number of ecological and economic projects and studies. The following publications tackle these research areas:

[1] M. Halla, F. Schneider and A. Wagner: "Satisfaction with democracy and collective action problems: The case of the environment", in Public Choice, Vol. 155, No. 1, pp. 109-137, 2013.

[2] G. Kirchgässner and F. Schneider: "On the political economy of environmental policy", in Public Choice, Vo. 115, No. 3, pp. 369-396, 2003.

[3] A. Kollmann and F. Schneider: "Warum ist die Umweltpolitik in repräsentativen Demokratien unzureichend? Eine Public Choice Analyse", in Björn Frank (ed.), Glaube und Rationalität in der Krise - Symposium zu Ehren von Hans G. Nutzinger, Marburg: Metropolis, pp. 151-200, 2001.

[4] A. Kollmann, J. Reichl and F. Schneider: "Who is willing to pay for the environment in the EU – An empirical analysis", in Euroeconomica, Vol. 31, No. 5, pp. 15-27, 2012.

[5] F. Schneider and H. Steinmüller Horst: "Forum Econogy 2011", Linz: Trauner, 2011.

[6] F. Schneider, H. Steinmüller and A. Hauer: "Energiewirtschaft, Jahrbuch 2012, Wien: NWV, 2012.

[7] F. Schneider and J. Volkert: "No chance for incentive oriented environmental policies in representative democracies? A Public Choice analysis", in Ecological Economics, Vol. 31, No. 1, pp. 123-138, 1999.

[8] F. Schneider and H. Weck-Hannemann: "Why is economic theory ignored in environmental practice", in Applied Research in Environmental Economics, Vol. 31, No. 3, pp. 257-275, 2005.

Competencies

The Department of Economics at the JKU Linz is committed to academic research and teaching on a high level of quality which meets the standards set by leading universities, both domestically and in international comparison. Our teaching is firmly rooted in our research standing and competence. Through its activities, the Department aims to contribute to the solution of today's most important economic problems.

Proponent

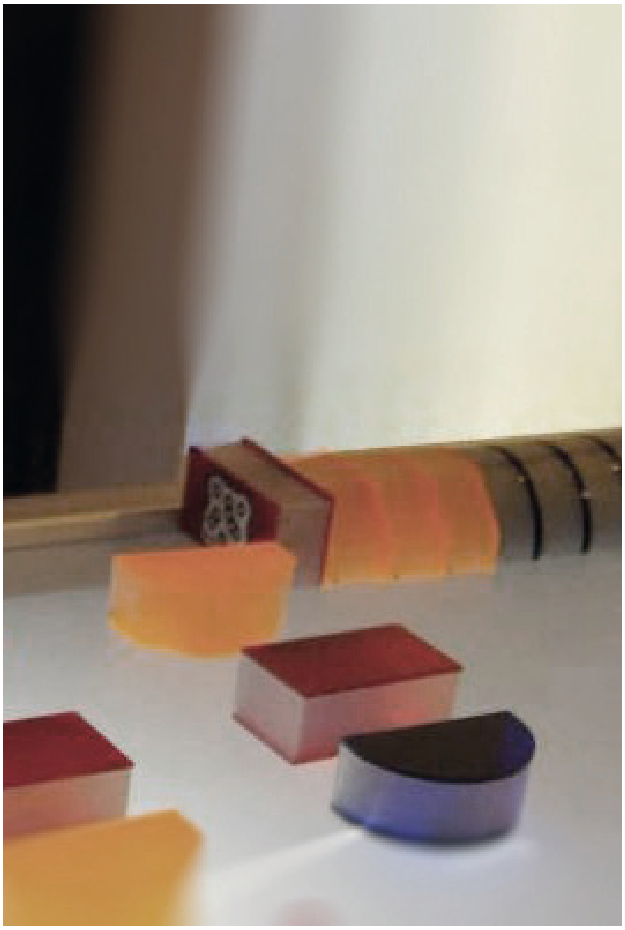
O.Univ.-Prof. Mag.Dr.h.c. Friedrich Schneider
Department of Economics

friedrich.schneider@jku.at
www.econ.jku.at/schneider

Keywords

Traditional Welfare Measure, Future Orientated Welfare Measure, Ecology, Economics, Happiness

Dynamic Capabilities and Business Intelligence



"Intertwining business processing and knowledge processing due to the selected approach will result in novel learning technologies, allowing stakeholders to articulate knowledge and make them active parts of agility management in organizations."

Christian Stary

Focus Line 5:

Product Lifecycle Management and Product Ecosystems

Coordinator:

O.Univ.-Prof. DI Dr. Christian Stary
Department of Business Informatics - Communications Engineering

christian.stary@jku.at
http://www.ce.uni-linz.ac.at/de

Research Focus

- Learning Process Design: Intertwining E-Learning and Organizational Learning
- Dynamic Capability Development of Individuals and Collectives.
- Articulation Work: Enable Stakeholders to Reflect Existing Organization of Work and Develop Prospects for Change.
- Knowlege-Based Guided Analytics
- Reference Modeling in Business Analytics

Vision

Dynamic capabilities are developed in **integrated business process** and **knowledge environments**, triggering reflected **change management processes** (www.valuenetworksandcollaboration.com). As stakeholders operate in complex adaptive systems they use features for (1) self-organized knowledge articulation, (2) sharing and reflection, and (3) business transformation (cf. [3]). They are qualified on-the-fly intertwining social media and cognitive learning interactions.

Business analysts articulate their comprehensive tacit knowledge and codify it in analytics applications in a semi-structured and iterative way. Proper tool support guides them (1) on how to proceed in the analysis process, (2) on which multiple rounds of specific questions (or hypothesis) to investigate, (3) on which selection criteria data are to be viewed, and (4) on which dimensions data are to be compared. Our vision is an analytics framework that provides analytical services for modelling, representation, and sharing of knowledge about analysis processes and associated guidance rules in a semantic layer and for reasoning over this knowledge to produce relevant guidance during analysis. The framework supports developing an analytics environment that integrates the semantic layer in a three-layered analysis framework to the visualization layer and to the data layer (provided by a relational data warehouse).

Approach

Dynamic capabilities require operational procedures beyond traditional management activities, once organizations become agile. **Effective development life cycles** provide a combined single- and double loop framework for developing organizations, addressing both, knowledge processing, and business processing (www.kmci.org). Yet, implementing development life cycles is often a disruptive effort, whereby the knowledge creation and processing environment is only loosely coupled with the business processing environment. This situation significantly constrains change management, in particular when surviving knowledge claims should be implemented in the business processing environment in a seamless way. The anticipated support for organizational designers combines knowledge claim formulation, evaluation, and non-disruptive knowledge integration into a business process environment. A corresponding tool chain is based on an open-format stakeholder articulation capturing values and business semantics, impact and value creation analysis, and finally, business process modelling and execution. The latter is essential for stakeholders to experience changes at the process execution level before putting them to operation. Moreover, it allows seamless roundtrip engineering based on cognitive learning processes coupled with social media interaction [3, 6].

State-of-the-art techniques for **business analytics** lack a high-level conceptual representation of analysis processes expressed in business terms and semantic structures between data views (such as drill-down or narrow-down relationships) and associated guidance rules. Therefore the challenge we face is not only to complement existing BI technology but to lay the foundations for modelling and representing knowledge about analysis processes in explorative data analysis. Reference modelling has been applied in the areas of business process modelling and data warehousing to share commonalties across a domain. Reference models are adjusted on deployment through modifying the reference model by changes, additions and deletions in a way to maintain overall system functionality. Again, corresponding reference modelling and adjustment techniques are unknown for analytical processes and rudimentary for ontologies.

In a **knowledge-based approach**, knowledge about business terms (upon which analytical queries are based), analysis situations, semantic data dependencies between analysis situations, and tacit knowledge on how to best proceed in a given analysis situation are captured explicitly in a declarative form by ontologies, ontology-based analytical queries, semantic relations between analytical queries and query terms, and rules (cf. [1,5]). Knowledge-based Guided Analytics will represent knowledge about "how to analyse" by semi-structured analysis graphs that describe declaratively how analysis situations of an analysis process relate to each other by analytical data relationships (such as "narrow down to …") and attached business terms (such as "… to VIP customers") of a business term ontology. Associated guidance rules will capture knowledge in the form of "condition-action" rules for providing active guidance on how to proceed in a given analysis. They are defined over analysis situations, data relationships, and ontology concepts (representing business terms).

The elicitation and explicit representation of knowledge about which data are inspected and how they relate semantically has been successfully applied in related domains such as the development of data-intensive web applications. WebML [2] for example, has introduced a navigation model layer between the data layer and the presentation layer. The navigation model captures (a) which data are to be presented on the web, irrespective of its actual visualization, and (b) how different data sets to be represented relate to each other. This is described declaratively in terms of high-level, conceptual navigation operators rather than by low-level SQL queries. The envisioned semantic layer for guided analytics provides counterpart functionality in the analytics domain. However, it is semantically richer by relating navigation to business terms (in an ontology) and capturing knowledge about analysis decision making. This richness can be exploited to provide guidance in similar analytical situations through reasoning.

Impact

Intertwining business processing and knowledge processing due to the selected approach will result in novel learning technologies, allowing stakeholders to articulate knowledge and make them active parts of agility management in organizations. Besides the scientific impact (top journal papers) business operations can be supported effectively to build dynamic capabilities (practical impact), sustaining high level services and industry partnerships (societal impact). In particular, the impact of using a **knowledge-based approach** to **data analytics** is: (1) The quality of work of business analysts will improve. Business analysts will be enabled to deliver high-quality analysis more quickly and more easily. They are relieved from remembering background knowledge and can thus better concentrate on critical analysis decisions. (2) Moreover, the envisioned approach will provide cross-system personalisation and knowledge-reuse. (3) Industry benefits of the usage of a knowledge-based approach in explorative data analysis. The re-use of knowledge about analysis processes will be the basis of more cost efficient and easier software development for future analytical products. (4) The approach will contribute to improve working conditions of recipients of analytical reports. Better information access and guidance will lead to timely and better informed decisions. The business analysis task is simplified and managers can be supported by context-aware, fine-grained and targeted analysis reports. Important analysis knowledge can be carried over between different but similar production processes making it more likely and easier to detect and identify critical or costly issues. Specific reference models may be defined that guide the analyst to improve production processes as to energy efficiency, pollution reduction, or waste avoidance.

References

[1] S. Anderlik, B. Neumayr and M. Schrefl: "Using Domain Ontologies as Semantic Dimensions in Data Warehouses", in Proceedings of the 31st International Conference on Conceptual Modeling (ER 2012), LNCS, Vol. 7532, pp. 88-101, Springer, 2012.

[2] S. Ceri, M. Brambilla and P. Fraternali: "The history of WebML: lessons learned from 10 years of model-driven development of web applications", in Conceptual Modeling: Foundations and Applications, LNCS, Vol. 5600, pp. 273-292, Springer, 2009.

[3] A. Fleischmann, W. Schmidt, C. Stary, S. Obermeier and Egon Börger: "Subject-oriented Business Process Management", Berlin: Springer, Open Book, 2012.

[4] M. Neubauer, S. Oppl, C. Stary, G. Weichhart: "Facilitating Knowledge Transfer in IANES – A Transactive Memory Approach", in R.J. Howlett, B. Gabrys, K. Musiat-Gabrys and J. Roach (eds.), Proceedings of the International Conference on Innovation through Knowledge Transfer (innovationKT-2012), Smart Innovation and Software Technology, Vol. 18, pp. 39-50, London: Springer, 2013.

[5] T. Neuböck, B. Neumayr, M. Schrefl and C. Schütz: "Ontology-driven Business Intelligence for Comparative Data Analysis", in Proceedings of the 3rd European Business Intelligence Summer School (eBISS 2013), LNBIP, Vol. 172, Springer, 2014. pp. 77-120

[6] C. Stary: "Non-disruptive Knowledge & Business Processing in Knowledge Life Cycles – Aligning Value Network Analysis to Process Management", in Journal of Knowledge Management, Vol. 18, No. 4, Emerald, 2014.

Competencies

The Department of Business Informatics – Communications Engineering coordinates a variety of fundamental and applied international research and development efforts, among them: Subject-Orientation for People-Centered Production (EU-FP 7 NMP-ICT-FoF Programme) introduces a process middleware for dynamic intertwining production control and business processes (SO-PC-Pro. 609190); IANES (Interactive Acquisition, Negotiation and Enactment of Subject-oriented Business Process Knowledge - FP 7 People Programme - Industry-Academia Partnership and Pathways 286083, www.ianes.eu) the KLC (Knowledge Lifecycle) implements the Knowledge LifeCycle (KLC) according to the envisioned organizational development approach. The SURGEOM Summer School educates on subject-driven role-guided externalization of organizational models (FP 7 Lifelong Learning Programme – Erasmus IP 230/20/12, www.surgeom.eu), whereas FARAW (Facilitating Articulation and Reflection about Work 2012-1-AT1-LEO05-06978, www.faraw.eu) trains for skilled and informed articulation of work knowledge.

The Department of Business Informatics – Data & Knowledge Engineering (DKE) participated in the project SemCockpit: An Ontology-Driven, Interactive Business Intelligences Tool for Comparative Data Analysis (FFG, FIT-IT 829594). Its results comprise the use of (external) ontologies of business terms to define BI analysis queries and the use of judgment rules (to capture knowledge about results of data comparisons. DKE gained further experience in the use of semantic technologies and process modelling as partner investigator in the project "Dynamic Semantic Interoperability of Business Processes" (Australian Research Council, DP0988961, 2008-2011). DKE participates with Frequentis (Vienna), Austro Control (Vienna), and EuroControl (Brussels) in collaborative research project employing a knowledge-based approach to the management of aeronautical information, "SemanticNOTAMs: Ontology-based representation and semantic querying of Digital Notices to Airman" (FFG, TAKE-OFF, 2014-2016).

Proponents

O.Univ.-Prof. DI Dr. Christian Stary
Department of Business Informatics - Communications Engineering

christian.stary@jku.at
http://www.ce.uni-linz.ac.at/de

O.Univ.-Prof. DI Dr. Michael Schrefl
Department for Business Informatics - Data & Knowledge Engineering

schrefl@dke.uni-linz.ac.at
http://www.dke.uni-linz.ac.at/

Keywords

Networked Embedded Systems, Complex Systems, Self-Organisation, Collective Adaptive Systems, Internet of Things, Business and Data Analytics

Authors

O.Univ.-Prof. Dr. Wolfgang Amrhein
Institute of Electric Drives and Power Electronics

Short Biography Wolfgang Amrhein joined JKU in 1994 as Director of the Institute of Electrical Drives and Power Electronics. From 2001-2007 he was Scientific Director of the Kplus Center of Competence. He is Area Coordinator for ‚Mechatronic Design of Machines and Components' of the Competence Center for Excellent Technologies and Director of the JKU HOERBIGER Research Institute of Smart Actuators

Univ.-Prof. Dr. Johann Bacher
Institute of Sociology - Department of Empirical Social Science Research

Short Biography Johann Bacher is Head of the Department of Empirical Social Science Research and Deputy Head of the Centre for Psychology & Law and for Criminology. Currently he serves as Dean of the Faculty of Social Sciences, Economics and Business. He is an expert for methods in empirical social research and well renowned for his book on cluster analysis in social sciences.

A.Univ.-Prof. Mag. Dr. Robert Bauer
Institute of Organization and Global Management Studies

Short Biography Robert M. Bauer is professor of Organization and Innovation. His research focuses on the management of innovation processes and the enhancement of creativity in industrial contexts — including the potential and risk in integrating management with art and design. He was a visiting professor for several years at the University of Toronto's Rotman School of Management, a leading institution in the field of 'Design Thinking'.

Univ.-Prof. Dr. Siegfried Bauer
Institute of Experimental Physics - Soft Matter Physics Department

Short Biography Siegfried Bauer joined JKU in 1997. He heads the Department of Soft Matter Physics. His main research topics are Soft-matter physics; dynamics of glass-transitions; memory effects; Thermal, electrical and optical properties of organic materials, and Applications of organic materials in sensors and photonics. He received an ERC Advanced Grant for the project "Soft-Map".

Univ.-Prof. Dr. Oliver Bimber
Institute of Computer Graphics

Short Biography Oliver Bimber is Head of the Institute of Computer Graphics at JKU Linz. Earlier affiliations include the IBM T.J. Watson Research Center (USA) and Fraunhofer Center for Research in Computer Graphics (USA). He co-authored the books "Displays: Fundamentals and Applications" and "Spatial Augmented Reality". The VIOSO GmbH was founded in his group.

Univ.-Prof. Mag. Dr. Karl Dörner
Institute of Production and Logistics Management

Short Biography Karl Dörner joined JKU in 2011 as Head of the Institute of Production and Logistics Management. His main research focus is Computational Logistics. He developed innovative methods for delivering perishable cargos, bulky goods, garbage collection and passenger transportation. His findings were published in more than 70 refereed papers and some of them are in use successfully.

Assoz.Univ.-Prof. Dr. Dmitry Efrosinin
Institute of Stochastics

Short Biography Dmitry Efrosinin obtained a Master Degree in Mathematics in 2000 from the Moscow University. He was a research fellow at Trier University, Department of Informatics in 2001-2002.He habilitated in 2011 at JKU Linz. In 2013 he defended the doctor thesis at the Institute for Control Sciences, Moscow. Since 2012, he is associated Professor at the Institute of Stochastics, JKU.

Univ.-Prof. DI Dr. Alexander Egyed M.Sc.
Institute of Software Systems Engineering

Short Biography Prof. Dr. Egyed heads the Institute of Software Systems Engineering (ISSE) at the JKU Linz, Austria. He received his Doctorate from the University of Southern California, USA and previously worked at Teknowledge Corporation, USA and the University College London, UK. Dr. Egyed was recognized among the Top 10 scholars in software engineering and his work has received numerous awards.

Univ.-Prof. Mag. Dr. Alois Ferscha
Institute of Pervasive Computing

Short Biography Alois Ferscha joined JKU in 2000 and heads the Institute of Pervasive Computing. Currently he is focused on Pervasive and Ubiquitous Computing, Networked Embedded Systems, Embedded Software Systems, Wireless Communication, Multiuser Cooperation, Distributed Interaction and Distributed Interactive Simulation. He has led several international EU funded projects.

Univ.-Prof. MMag.Dr. Matthias Fink
IFI - Institute of Innovation Management

Short Biography Matthias Fink is head of the Institute of Innovation Management (IFI) and a Professor for Innovation and Entrepreneurship at the IIMP at ARU Cambridge, UK. He worked as a Professor for International Small Business Management and Innovation at Leuphana Univerity Lüneburg and was Head of the Research Institute for Liberal Professions at WU Vienna. Matthias holds a Ph.D. and a postdoctoral qualification from WU Vienna.

A.Univ.-Prof.in Mag.a Dr.in Iris Fischlmayr
Department of International Management

Short Biography Iris Fischlmayr is associate professor and head of the Department of International Management. She is visiting professor for International Human Resource Management at the University of Melbourne, Australia. Iris has been co-developer of a virtual training tool based on a real-time based online business simulation involving universities and multinational companies worldwide.

Mag. Johannes Gartner
IFI - Institute of Innovation Management

Short Biography Johannes Gartner is a researcher and Ph.D candidate at the Institute of Innovation Management (IFI) at the JKU Linz and is studying computer engineering at the UAS Mittweida, Germany. He holds a MA from WU Vienna and has gained professional experience in management positions in international IT companies. His PhD project is funded by the Internet Foundation Austria.

A.Univ.-Prof. Mag. Dr. Paul Grünbacher
Institute of Software Systems Engineering

Short Biography Paul Grünbacher is an Associate Professor at JKU Linz. He heads the Christian Doppler Laboratory for Monitoring and Evolution of Very-Large-Scale Software Systems, a 7-year research project co-funded by industrial partners. His research interests include software product lines, requirements engineering, and software evolution.

Dr. Michael Gusenbauer
IFI - Institute of Innovation Management

Short Biography Michael Gusenbauer is researcher at the Institute of Innovation Management (IFI), where his research interest is at the intersection of international business and innovation. He investigates offshoring of innovation in small and medium-sized enterprises. In his teaching Michael offers insights into business model innovation.

Univ.-Prof. DI Dr. Kurt Hingerl
Center for Surface and Nanoanalytics (CSNA-ZONA)

Short Biography Kurt Hingerl is leading the JKU Centre for Surface and Nanoanalytics since 2008. From 2003-2010 he was Head of the Christian Doppler Laboratory for Surface Optics and Photonics. His main research topics are – partly in cooperation with different companies- modelling fundamental properties of materials and interfaces and developing optical in-situ, in-process compatible analysis techniques.

Univ.-Prof. Dr. Sepp Hochreiter
Institute of Bioinformatics

Short Biography Sepp Hochreiter is Head of the Institute of Bioinformatics at the JKU Linz/Austria since 2006. From 2001-2006 he was Assistant Professor at the TU Berlin and from 1999-2001 he was postdoc with Prof. Mozer at the University of Colorado, Boulder. In 1999 he graduated with a PhD in computer science at the TU Munich where he was research associate from 1994-1999.

A.Univ.-Prof. Mag. DDr. Johann Höller
Department of Data Processing in Social Sciences, Economics and Business

Short Biography Johann Höller heads the Department of Data Processing in Social Sciences, Economics and Business, JKU Linz, Austria and is chair of the Curricular Committee Webscience and Digital Business Management. He has a PhD in business administration and law and is Professor for information processing and information law. His research focus is on digital business and information law.

Univ.-Prof. Dr. Mario Huemer
Institute of Signal Processing

Short Biography Mario Huemer is the Head of the Institute of Signal Processing (ISP). His research interests are adaptive and statistical signal processing, signal processing architectures and implementations, as well as mixed signal processing with applications in communications, radio frequency and baseband integrated circuits, battery- and power management for mobile devices, sensor and biomedical signal processing.

O.Univ.-Prof. DI Dr. Dr.h.c. Hans Irschik
Institute of Technical Mechanics

Short Biography Hans Irschik heads the Institute of Technical Mechanics since 1994. He served as Vice Rector of Research from 1995-2001, and as Chair of the Senate from 2009-2013. He is a Full Member of the Austrian Academy of Sciences, and he also works with several other institutions engaged in research funding. He has contributed to numerous renowned journals, books and conferences.

Univ.-Prof. DI Dr. Bernhard Jakoby
Institute of Microelectronics and Microsensors

Short Biography Bernhard Jakoby was appointed Professor of Microelectronics at the JKU in 2005. Former affiliations include the University of Ghent (BE) as Erwin Schrödinger Fellow, TU Delft (NL), and the Automotive Electronics Division of the Robert Bosch GmbH (DE). He is currently working in the field of microsensors and microsystems.

Univ.-Prof. Mag. Dr. Bert Jüttler
Institute of Applied Geometry

Short Biography Bert Jüttler studied Mathematics in Dresden and Darmstadt (DE). He obtained is doctoral degree in 1994 and his habilitation in 1998. After stations as postdoc in Dundee (UK) and Lecturer in Darmstadt (DE), he was appointed as Professor at JKU in 2000. His research interests include Computer Aided Geometric Design, Computational Geometry and Isogeometric Analysis.

Univ.-Prof. Dr. Norbert Kailer
Institute of Entrepreneurship and Organizational Development

Short Biography Norbert Kailer is the head of the Institute of Entrepreneurship and Organizational Development. He is Board Member of the Linz-based academic pre-Incubator "Akostart OÖ". Norbert was a professor for Personnel and Qualification at the Ruhr-University Bochum. He focusses on Entrepreneurial Learning, Competency Development, University-Industry Cooperation, Development of SME, Entrepreneurial Intention.

Assist.-Prof.in Mag.a Dr.in Elisabeth Katzlinger-Felhofer
Department of Data Processing in Social Sciences, Economics and Business

Short Biography Elisabeth Katzlinger-Felhofer is Assistant Professor at the Department of Data Processing in Social Sciences, Economics and Business at JKU. She has degrees in business administration and business education and received her doctorate in business administration from the JKU Linz (AT). Her research focus is on technology enhanced learning and digital business.

Univ.-Prof. Dr. Thomas Klar
Institute of Applied Physics (IAP)

Short Biography is a Professor for Applied Physics at JKU since 2010. Before, he was Associate Professor at TU Ilmenau (DE), since 2007. In 2007 he was awarded the venia legendi from Ludwig-Maximilians-Univeristy after he received a PhD in Physics from University of Heidelberg in 2001 for his research on STED microscopy at the Max-Planck-Institute for Biophysical Chemistry (DE).

Univ.-Prof. Dr. Erich Peter Klement
Department of Knowledge-Based Mathematical Systems

Short Biography Erich Peter Klement is Professor of Mathematics at JKU since 1993 and heads the Department of Knowledge-Based Mathematical Systems. His research areas are Foundations of Fuzzy Logic and Fuzzy Control, Triangular Norms, Measure and Integration Theory, Applications to Probability and Game Theory.

Univ.-Prof. Dr. Reinhold Koch
Institute of Semiconductor and Solid State Physics

Short Biography Reinhold Koch is Head of the Solid State Physics Division. Former affiliations include the Free University and the Paul Drude Institute in Berlin as well as the Stanford/NASA Joint Institute of Surface and Microstructure Research, USA. His research interests are ferromagnet/semiconductor hetero- and nanostructures and for spin- and magnetoelectronics as well as the development of STM-based magnetic resonance for single spin detection in molecular magnets.

A.Univ.-Prof. DI Dr. Josef Küng
Institute of Application Oriented Knowledge

Short Biography Josef Küng is Associate Professor at the Institute of Application Oriented Knowledge Processing (FAW). His core competencies cover Information Systems, Knowledge Based Systems, Decision Support Systems, Semantic Technologies and Similarity Queries where he has published a fair number of scientific papers and managed numerous projects with industry.

O.Univ.-Prof. DI Dr. Ulrich Langer
Institute of Computational Mathematics

Short Biography Ulrich Langer heads the Institute of Computational Mathematics since 1993. Since 2003 he is Deputy Director of the "Radon Institute for Computational and Applied Mathematics" (RICAM) of the Austrian Academy of Sciences and leads the research group "Computational Methods for Direct Field Problem".

Univ.-Prof. Mag. Dr. Gerhard Larcher
Institute of Financial Mathematics

Short Biography Gerhard Larcher heads the Institute of Financial Mathematics since 2000 and is speaker of the FWF Special Research Area "Quasi-Monte Carlo-Methods: Theory and Applications". He authored more than 100 publications and works in the areas of asset management, risk management, derivative trading strategies with intensive industry co-operations.

Mag.a Dr.in Daniela Maresch LL.M.
IFI - Institute of Innovation Management

Short Biography Daniela Maresch an assistant professor at the Institute of Innovation Management (IFI). She holds a PhD in Business and an LL.M. in Business Law from WU Vienna. She gained practical experience in financial reporting and in corporate law working for Viennese law firm. In research, she employs her interdisciplinary expertise into topics at the intersection of innovation, finance and business law.

Univ.-Prof. DI Dr. Jürgen Miethlinger MBA
Institute of Polymer Extrusion and Compounding

Short Biography Jürgen Miethlinger heads the Institute of Polymer Extrusion and Compounding since 2009. Former affiliations include Lenzing AG, SML Maschinenges.mbH and Poloplast. Since 2004 he is CTO of the Poloplast Group. His research interests includes Polymer Processing Technologies, Screw Extrusion Performance, Multilayer and Hybrid Polymeric Systems, Compounding, Recycling and Additive Manufacturing.

O.Univ.-Prof. DI Dr. Dr.h.c. Hanspeter Mössenböck
Institute of System Software

Short Biography Since 2004, Hanspeter Mössenböck heads the Institute of System Software. He is Member of the University Council (university council) at TU Graz, Member of the Advisory Board of the European Forum Alpbach and Associate Editor of JOT (Journal of Object Technology). From 2006 to 2013 he was Head of the Christian Doppler Laboratory for Automated Software Engineering.

Univ.-Prof. Dr. Werner Müller
Department of Applied Statistics

Short Biography Werner G. Müller is currently Deputy Head of the Department of Applied Statistics at the JKU and President of the Austrian Statistical Society. His research interests are in the areas of experimental design and spatial statistics. He is author of the book "Collecting Spatial Data" and contributed to more than 80 other publications. He serves as Coeditor of Statistical Papers (Springer) since 2010.

A.Univ.-Prof. DI Dr. Tim Ostermann
Institute of Integrated Circuits

Short Biography Timm Ostermann is Associate Professor at the Institute of Integrated Circuits (RIIC). His research interests include analogue-, Mixed-Analogue-/digital- and RF-IC-Design, circuit simulation and modelling, EMC at IC level and characterization of new technologies (e.g. polymer).

Univ.-Prof. Dr. Peter Paule
Research Institute of Symbolic Computation

Short Biography Peter Paule is Director of the Research Institute of symbolic Computation (RISC) and of the FWF Doctoral Program "Computational Mathematics" at JKU. He is member of the Academia Europaea and Fellow of the American Mathematical Society. His research interests include computer algebra and algorithmic mathematics in connection with combinatorics and special functions.

A.Univ.-Prof. Mag. Dr. Johannes D. Pedarnig
Institute of Applied Physics (IAP)

Short Biography Johannes Pedarnig graduated in Experimental physics at KFU Graz (AT), obtained his PhD in Physics at LMU Munich (DE), and his venia docendi in Experimental Physics at the JKU Linz. He is Head of the Christian Doppler Laboratory for Laser-Assisted Diagnostics (2007-2014). His research topics are Laser-based element analysis of complex materials and Growth of multi-component oxide thin films.

Univ.-Prof.in Dr.in Susanne Pernicka
Institute of Sociology - Department of Economic and Organisational Sociology

Short Biography Susanne Pernicka is Head of the Department of Economic and Organisational Sociology since 2010. Former affiliations include the University of Oldenburg, the University of California, Berkeley and the University of Vienna. Her research interests include Employment Relations, Industrial and Economic Sociology, Sociology of Organizations, Professions and of European Societies.

O.Univ.-Prof. Mag. Dr. Helmut Pernsteiner
Department of Finance - Corporate Finance

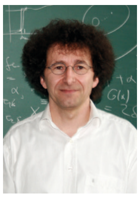
Short Biography Helmut Pernsteiner is Head of the Department of Finance and Deputy Head of the Research Institute of Banking. The research focus is on financing in emerging markets and financing of family businesses, as well as mergers and acquisitions. In the 1990s he was working for a Viennese investment bank. He is Director of several Post Graduate Programs in Financial Management and Insurance.

A.Univ.-Prof. Mag. Dr. Reinhold Plösch
Department of Business Informatics - Software Engineering

Short Biography Reinhold Plösch is Associate Professor at the Department of Business Informatics/Software Engineering. His research interests are Quality of Software Products and Software Development Processes, Requirements Engineering, Distributed Systems, Internet Applications, Mobile Agents, Object-oriented Programming Languages and Object Oriented Design.

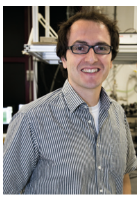
O.Univ.-Prof. DI Dr. Gustav Pomberger
Department of Business Informatics - Software Engineering

Short Biography Gustav Pomberger is Professor for Software Engineering and heads the Department of Business Informatics/Software Engineering at the JKU Linz since 1987. Before, he was Professor of Computer Science at the University of Zürich (CH). He led the C. Doppler Research Laboratory for Software Engineering (1992-99). Since 2002, he is Senior Fellow of the C. Doppler Research Society.



Univ.-Prof. Dr. Ronny Ramlau
Institute of Industrial Mathematics

Short Biography Ronny Ramlau heads the Industrial Mathematics Institute and the Transfer Group of the Johann Radon Institute for Computational and Applied Mathematics (RICAM). His research interests include nonlinear inverse problems, inverse problems in astronomy, regularization methods, iterative methods, medical imaging and mathematical methods in industry.



Univ.-Prof. Dr. Armando Rastelli
Institute of Semiconductor and Solid State Physics

Short Biography Armando Rastelli heads the Institute of Semiconductor and Solid State Physics since 2012. Former affiliations include ETH Zürich, Max-Planck-Institut für Festkörperforschung and IFW Dresden. His research interests are Semiconductor Quantum Dot (QD) structures, Strain-tunable QD-devices and Thermoelectric properties of nanostructured semiconductors (Ge/SiGe).

O.Univ.-Prof. DI Dr. Wolfgang Samhaber
Institute of Process Engineering

Short Biography Wolfgang Samhaber is Head of the Institute of Process Engineering since 1997. Main research topics include Environmental process engineering, Nanofiltration and high pressure reverse osmosis, Separation processes with liquid CO2, Characterization and modification of polymer membranes, and Synthesis and characterization of emulsion polymerization.

O.Univ.-Prof. DI Dr. Rudolf Scheidl
Institute of Machine Design and Hydraulic Drives

Short Biography Rudolf Scheidl obtained the PhD of Engineering Sciences at TU Vienna (AT). He is Professor for Mechanical Engineering at JKU Linz since 1990. His industrial research and development experience include agricultural machinery (Epple Buxbaum Werke) and continuous casting technology (Voest Alpine Industrieanlagenbau). Current research topics are hydraulic drive technology and mechatronic design.

O.Univ.-Prof. DI Dr. Kurt Schlacher
Institute of Automatic Control and Control Systems Technology

Short Biography Kurt Schlacher joined JKU as Professor for Automatic Control in 1992 and heads the Institute of Automatic Control and Control Systems Technology. His field of research is Modelling and Control of nonlinear systems with respect to industrial applications applying differential geometric and computer algebra based methods.

O.Univ.-Prof. Mag. Dr. h.c. Friedrich Schneider
Department of Economics

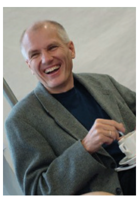
Short Biography Friedrich Schneider is Professor of Economics at JKU Linz. He obtained his PhD in Economics from the University of Konstanz (DE) and has held numerous visiting and honorary positions. He was the European editor of Public Choice and has published extensively in leading Economics journals (e.g. The Quarterly Journal of Economics, The Economic Journal, Kyklos). He published 70 books and 384 scientific articles.

O.Univ.-Prof. DI Dr. Michael Schrefl
Department for Business Informatics - Data & Knowledge Engineering

Short Biography Prof. Schrefl heads the Department of Business Informatics/Data & Knowledge Engineering at JKU, with projects in business intelligence and semantic systems, and authored over 100 refereed scientific publications. Former affiliations include Vanderbilt University (Fulbright Scholarship), TU Wien, GMD-IPSI (now Fraunhofer Darmstadt) and the University of South Australia.

Univ.-Prof. DI Dr. Andreas Springer
Institute of Communications Engineering and RF-Systems

Short Biography Andreas Springer is Head of the Institute of Communications Engineering and RF-Systems at JKU Linz. His current research interests are focused on wireless communication systems, architectures and algorithms for multi-band/multi-mode transceivers, UMTS/HSDPA/LTE, and wireless sensor networks. In these fields, he has published more than 180 papers, one book, and two book chapters.



O.Univ.-Prof. DI Dr. Christian Stary
Department of Business Informatics - Communications Engineering

Short Biography Christian Stary heads the Institute of Business Informatics/Communications Engineering, the Knowledge Management Competence Center and the Post Graduate Program “Applied Knowledge Management”. He works on the development and evaluation of socio-technical systems, integrating Distributed Computing, Usability Engineering, Knowledge Management and Software Engineering.

Univ.-Prof. DI Dr. Georg Steinbichler
Institute of Polymer Injection Moulding and Process Automation

Short Biography Since 2009, Georg Steinbichler heads the Institute of Polymer Injection Moulding and Process Automation. He obtained his PhD in Polymer Technology from the Friedrich-Alexander-University Erlangen-Nuremberg and is member of the scientific alliance of the university professors of polymer technology in Germany. At the ENGEL group – global leader in the development of production systems for polymer injection moulding - he is vice president R&D Technologies.

Univ.-Prof. DI Dr. Andreas Stelzer
Institute of Communications Engineering and RF-Systems

Short Biography Andreas Stelzer heads the department for RF-Systems and a Christian Doppler Research Laboratory for Integrated Radar Sensors. His research is focused on microwave sensor systems for industrial and automotive applications, RF-subsystems, mm-wave imaging, local positioning systems, SiGe-based circuit design, and digital signal processing for precise sensor signal evaluation.

Assist.-Prof. DI Dr. Marc Streit Bakk.
Institut of Computer Graphics

Short Biography Marc Streit finished his PhD at TU Graz in 2011. At JKU he is leading the Visual Data Analysis group. He spent a part of the year 2012 as a visiting researcher at Harvard Medical School. In 2014 he received a Fulbright scholarship for research and lecturing at Harvard University. He won multiple best paper and runner-up awards at some of the most renowned visualization conferences.

Ass.-Prof. DI Dr. Rainer Weinreich
Department of Business Informatics - Software Engineering

Short Biography Rainer Weinreich is associate Professor of Software Engineering at the Department of Business Informatics/Software Engineering and a senior research associate at the Software Competence Center Hagenberg. He has profound experience in applied software engineering research with national and international industrial partners. He is an expert on software architecture and design.

Univ.-Prof. DI Dr. Gerhard Widmer
Institute of Computational Perception

Short Biography Gerhard Widmer heads the Institute of Computational Perception, and leads the Intelligent Music Processing Group (OFAI, Vienna). His research interests are in the fields of Artificial Intelligence, Machine Learning, intelligent data analysis; in particular novel computational methods for music and musical signal analysis and understanding. He received the Austrian Wittgenstein Award (2009).

Univ.-Prof. DI Dr. Bernhard Zagar
Institute of Measurement Technology

Short Biography Bernhard Zagar heads the Institute of Measurement Technology. He (co-)authored more than 150 publications and was involved in more than 50 research projects. He is Chairman of IMEKO-TC2 (International Measurement Confederation, Technical Committee for Photonics).

O.Univ.-Prof. DI Dr. Klaus Zeman
Institute of Mechatronic Design and Production

Short Biography Klaus Zeman is Head of the Institute of Mechatronic Design and Production since 1996. His research interests are the modelling and simulation of specific manufacturing processes, model based mechatronic design, design science, and machine dynamics. Formerly, he worked for a renowned Austrian metallurgical plant supplier.

Index

Amrhein Wolfgang
Bacher Johann
Bauer Robert
Bauer Siegfried
Bimber Oliver
Dörner Karl
Efrosinin Dmitry
Egyed Alexander
Ferscha Alois
Fink Matthias
Fischlmayr Iris
Gartner Johannes
Grünbacher Paul
Gusenbauer Michael
Hingerl Kurt
Hochreiter Sepp
Höller Johann
Huemer Mario
Irschik Hans
Jakoby Bernhard
Jüttler Bert
Kailer Norbert
Katzlinger Elisabeth
Klar Thomas
Klement Erich Peter
Koch Reinhold
Küng Josef
Langer Ulrich
Larcher Gerhard
Maresch Daniela
Miethlinger Jürgen
Mössenböck Hanspeter
Müller Werner
Ostermann Timm
Paule Peter
Pedarnig Johannes
Pernicka Susanne
Pernsteiner Helmut
Plösch Reinhold
Pomberger Gustav
Ramlau Ronny
Rastelli Armando
Samhaber Wolfgang
Scheidl Rudolf
Schlacher Kurt
Schneider Friedrich
Schrefl Michael
Springer Andreas
Stary Christian
Steinbichler Georg
Stelzer Andreas
Streit Marc
Weinreich Rainer
Widmer Gerhard
Zagar Bernhard
Zeman Klaus

Univ. Prof. Dr. Alois Ferscha
Institute of Pervasive Computing

JOHANNES KEPLER UNIVERSITY LINZ
Altenberger Straße 69
4040 Linz, Austria

P +43 732 2468 4762
M +43 699 1111 1010

alois.ferscha@jku.at
www.pervasive.jku.at

ISBN 978-3-200-04583-5
9 783200 045835

JOHANNES KEPLER UNIVERSITÄT LINZ

1111
1010