Eingebettete interaktive Systeme: Zurück zur realen Welt

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Kurzfassung: Drahtlose Kommunikationstechnologien zur Realisierung lokaler und körpernaher Netzwerke, die breite Verfügbarkeit miniaturisierter Sensor und Aktuator Hardware sowie das überwältigende Wachstum globaler Netze (wie z.B. das Internet) haben die Etablierung und Verbreitung vernetzter eingebetteter Systeme in den letzten Jahren rasant beschleunigt. „Smarte Dinge“, das sind spontan vernetze, mobile, autonom agierende und drahtlos kommunizierende Endgeräte, sind Indikatoren einer total vernetzten Welt, in der potenziell alles mit allem interagiert. Diese Interaktion findet implizit –über eine Menge von Sensoren auf der Eingabeseite, bzw. einer Reihe von Aktuatoren auf der Ausgabeseite– statt. Mit der Integration unsichtbarer Informationstechnologie in Alltagsgegenstände und Lebensräume jedoch, werden diese auch zur Schnittstelle zu „unsichtbaren“ oder „versteckten“ Diensten, die scheinbar im Hintergrund arbeiten. Eingebettet interaktive Systeme erlauben somit eine Überbrückung von der relaen Welt hin zu einer digitalen Welt der unsichtbaren Dienste, ohne dass dafür traditionelle Ein-Ausgabegeräte wie Bildschirme und Tastaturen notwendig wären: Die Dinge selbst verkörpern Dienste, die Interaktion mit den Dingen ist gleichzeitig die Interaktion mit den Diensten für die sie stehen. Eingebettet interaktive Systeme wecken somit die Hoffnung einer Abkehr von traditionellen Interaktionsformen mit Computersystemen, „zurück“ zu einer Interaktion mit den Dingen der realen Welt.

Schlüsselwörter: Pervasive Computing, Ubiquitous Computing, Dinghafte Benutzungsschnittstellen, Umgebungsintelligenz, Augmented und Mixed Reality, Durchsichtsysteme.

Keywords: Pervasive Computing, Ubiquitous Computing, Tangible Interfaces, Smart Things, Augmented and Mixed Reality, See Through Systems.

Embedded Interactive Systems: Back to the Real World

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Abstract: The maturing of reliable wireless communication technologies for local and personal area networks, the broad availability of miniaturized sensor and actuator hardware technologies, and the tremendous growth of global networks like the Internet over the past years have accelerated the emergence of "networked embedded systems". So called "smart appliances", i.e. ad-hoc networked, mobile, autonomous, special purpose computing appliances have appeared, usually interacting with their environment implicitly via a variety of sensors on the input side, and actuators on the output side. With the embedding of invisible technology into everyday things and architectural spaces, things and spaces also become the interface to "hidden" or "invisible" computational services. Embedded interactive systems allow to mediate between the physical and digital (or virtual) world via natural interaction – away from the desktop displays and keyboards. The embedding of sophisticated sensor, actuator and wireless communication technologies, together with novel interface concepts for situated interaction (tangible interfaces, attentive interfaces) give rise for bringing the interaction with computers "back to the real world".

1 Introduction and Motivation

A vast manifold of heterogeneous, small, embedded and mobile devices has emerged in the pervasive and ubiquitous computing landscape, characterized by the autonomy of their programmed behaviour, the dynamicity and context-awareness of services and applications they offer, the ad-hoc interoperability of services and the different modes of user interaction upon those services [10]. This is mostly due to technological progress like the maturing of wireless networking, exciting new information processing possibilities induced by submicron IC designs, low power storage systems, smart material, and motor-, controller-, sensor- and actuator technologies, envisioning a future computing service scenario in which almost every object in our everyday environment will be equipped with embedded processors, wireless communication facilities and embedded software to percept, perform and control a multitude of tasks and functions. Since many of these objects will be able to communicate and interact with global networks and with each other, the vision of "context-aware" [8] smart appliances and smart spaces [29] – where dynamically configured systems of mobile entities by exploiting the available infrastructure and processing power of the environment – has become a reality. The individual utility of such services stems from being personalized, i.e. user centered and dynamically adapted to user preference, location aware, i.e. multimodal and multifunctional with respect to the environment, and time dependent, i.e. dynamic and with timely responsiveness. Common in the trend of context aware environments – often referred to as "smart appliances" or "smart spaces" – is that they interact with the user in a pro-active, autonomous, sovereign, responsible and user-authorized way. Common is also that the provision of their services is based on their ability of being aware of the presence of other objects or users, and being sensitive, adaptive and responsive to their needs, habits and emotions. Their services tend to become ubiquitously accessible via natural interaction. Embodied into real world objects like furniture, clothing, crafts, rooms, etc., those services are usually "invisible", i.e. cannot be perceived visually or orally, thus leaving the user "un-aware" of their presence.

We believe that the utility of many of those "invisible services" of smart appliances being better exploited when presented to the user in a more intuitive and natural way, thus raising the need for a better perception of smart environments by the user. To support people living in the real world populated with a variety of digital artefacts as created by the digital components in a smart environment, when acting, perceiving and interacting with objects in their environment, we propose a see-through based theatre experience of visual perception, seamlessly merging the artefacts of the real and the digital world.

We first relate our approach to the ubiquitous computing landscape in the next section (Section 2). In Section 3 we present DigiScope, the 6DOF (six degrees of freedom) visual see-through tablet we have developed to support an intuitive "invisible service" – or more generally: "invisible world" – inspection. In Section 4 we present a use case for DigiScope. The invisible services of the smart appliance "SmartCase" – which has been developed as a demonstrator for our contextware framework [11] – will be inspected via DigiScope.

2 Linking Physical and Virtual Worlds

Two prospective visions of future computing environments have induced a shift from the "one person with one computer" paradigm, which is based on explicit man machine interaction, towards a "Pervasive Computing" landscape, in which implicit interaction and cooperation is the primary mode of computer supported activity: (i) Weiser's Ubiquitous Computing vision [41] (since 1988) grounded on the massive deployed computers, where "*each person is continually interacting with hundreds of nearby interconnected computers without explicitly attending to them*", and (ii) Wellner's "Augmented Environments" [40] (since 1993), grounded on an interaction with computers (building a "virtual world") via accustomed physical/tangible artefacts or environments (out of the "physical world"). We look at these visions and related developments in more detail.

"The most profound technologies are those that disappear. They weave themselves into the fabric of everyday life until they are indistinguishable from it" was Mark Weiser's central statement in his seminal paper [41] in Scientific American in 1991. His conjecture, that "we are trying to conceive a new way of thinking about computers in the world, one that takes into account the natural human environment and allows the computers themselves to vanish into the background" has fertilized the embedding of ubiquitous computing technology into a physical environment which responds to people's needs and actions. Most of the services delivered through such a "technology-rich" environment are services adapted to context, particularly to the person, the time and the place of their use. Along Weiser's vision, it is expected that context-aware services will evolve, enabled by wirelessly ad-hoc networked, mobile, autonomous special purpose computing devices (i.e. "smart appliances"), providing largely invisible support for tasks performed by users. It is expected that services with explicit user input and output will be replaced by a computing landscape sensing the physical world via a huge variety of sensors, and controlling it via a manifold of actua-tors in such a way that it becomes merged with the virtual world. Applications and services will have to be greatly based on the notion of context and knowledge, will have to cope with highly dynamic environments and changing resources, and will need to evolve towards a more implicit and proactive interaction with users.

A second historical vision impacting the evolution of pervasive computing claimed for an intuitive, unobtrusive and distraction free interaction with technology-rich envi-ronments. In an attempt of bringing interaction "back to the real world" [40] after an era of keyboard and screen interaction, computers started to be understood as secondary artefacts, embedded and operating in the background, whereas the set of all physical objects present in the environment were started to be understood as the primary artefacts, the "interface". Instead of interacting with digital data via keyboard and screen, physical interaction with digital data, i.e. interaction by manipulating physical artefacts via "graspable" or "tangible" interfaces, was proposed. Inspired by the early approaches of coupling abstract data entities with everyday physical objects and surfaces like Bishop's Marble Answering Machine, Jeremijenko's Live Wire and Wellner's Digital Desk [40], tangible interface research [14] has evolved, where physical artefacts are considered as both (i) representations and (ii) controls for digital information. A physical object thus represents information while at the same time acts as a control for directly manipulating that information or underlying associa-tions. With this seamless integration of representation and control into a physical artefact also input and output device fall together. Placed meaningfully, such artefacts can exploit physical affordances suggesting and guiding user actions, while not compromising existing artefact use and habits of the user. Recent examples for "embodied interaction", where input and output are fused into physical object manipulation, include architecture and landscape design and analysis [25], object shape modeling interfaces using brick like blocks or triangular tiles [14].

This work aims at supporting "human to ubiquitous computer interaction" processes by bringing back visual clues to the user on how to interact. Once computers have disappeared from desks, hiding in the background, their services will most likely still be there. New artefacts and smart appliances [35] are evolving that "carry" invisible services, such that manipulating the appliance controls a service. Even if the service is not integrated into the artefact but merely "linked" to a background system [16], the manipulation of the physical object can manipulate their virtual representative on that background system respectively. To this end it is necessary to link the physical world with the virtual world [11], i.e. the linking of physical objects with their "virtual counterparts" [30].

A common problem of tangible interfaces is the lack of visual clues of the kind of services hidden in an artifact and how to access or use them. Since not all of those artefacts are designed (or even able) to provide their own visual interface, an annotation of the related physical objects with digital information appears appropriate [15]. The visualization of those annotations can be done in a situative way by means of virtual or mixed reality technologies. Mixed Reality (MR) environments according to Milgram's classification [22] are those in which real world and virtual world objects are presented together on a single display. It covers the whole reality-virtuality spectrum, involving the physical reality, augmented reality and virtual reality. Single user MR interfaces have been developed for computer aided instruction, manufacturing and medical visualization [4]. These applications have shown that MR interfaces can enable a person to interact with the real world in ways that have never been possible before, e.g. in the project MEDARPA [33] project.

The implementation of visual interfaces for MR applications usually involves the use of output devices that allow users to percept the world via coalesced physical and artificial views. The most prominent technologies to implement such interfaces today are video- and optical see-through systems, realized either as head-mounted- (HMD) or non-head-mounted displays. User experience however has revealed that such devices are very unnatural and klutzy in handling. We therefore follow an approach that allows for an obstruction-free perception of ubiquitous computing rich environments. Much like Paradiso's metaphor of a flashlight to "find" (tagged) objects in the "darkness" [20], and Koleva's metaphor of a handheld position and orientation sensitive 3D environment inspection pad [3], we propose a 6DOF optical see-through inspection tablet, to provide a seamless interface between real and digital artifacts. The metaphor of digital annotations for real world objects is exploited, displaying annotations along the line of sight to real world objects that are seen through a holographic display. The user gets the ability to interact with the virtual object and its digital information by viewing the corresponding real (physical) artefact.

3 Embedded Interactive System Example: DigiScope

The driving motivation for the design and implementation of a 6DOF see-through inspection tablet was to provide a seamless interface between real and digital artefacts, in order to create new and better human experience when observing the services of smart environments. Towards a seamless visual perception of the coexistence of a real world and its virtual augmentation, we exploit the metaphor of digital annotations for real world objects, and display these annotations along the line of sight to real world objects that are seen through the tablet.

The challenge for digital annotation visualization via a see-through display is to cope with the changes and interactions among physical and virtual world objects in a certain environment or scene in real-time. To be able to provide the necessary user fidelity, the monitoring and managing of objects in the scene demands mechanisms for real-time identification, positioning and tracking of physical objects, and needs adequate models of the objects of interest [39]. As an example for identification and annotation of real world objects with virtual hyperlinks, some researchers have developed systems that sense physical entities in the environment and map them to a web browser [26] [16]. Sensing technologies used for such linking and annotation purposes are infrared beacons, radio frequency ID tags (RFID) and bar codes, while the interaction with services in "smart spaces" is implemented based on the use of hand-held devices for the perception, resolution and manipulation of URIs (universal resource locators) of real world objects. Other approaches are using augmented reality system technology to enhance a person's view within a smart space by visually presenting the digital and real artefacts respectively. A typical approach is to annotate real objects with detailed virtual information in the users view [23], [28], [19]. Another possibility is to augment the real world with virtual objects like in [5], where a map is extended with a 3D surface of a landscape to give the user a more realistic impression. A portable augmented reality display for outdoors has been demonstrated in [32] [3] to allow for a (physical) historical site inspection by wheeling a cart-like inspection system through a flat terrain at slow walking pace. Augmented reality (AR) within a "smart space" can also provide alternative opportunities to manipulate digital artefacts [24].

We follow the mixed reality approach to display digital annotations of a physical reality, where the reality is perceived behind a see-through tablet. The tablet can be controlled by the spectator (user) in position (3D) and orientation (roll, pitch and yaw) respectively, while annotations are displayed on the tablet as decorations of the reality. Even objects invisible or hidden in reality (consider a shirt or a key ring hidden in a suitcase) can be made "visible" with appropriate annotations. The implementation options for such a see-through AR based smart environment inspection system ranges from various kinds of video see-through displays to optical see-through displays. Video see-through AR displays typically consist of a HMD (head-mounted display) that displays a real scene video that is captured in positional sync with the orientation of the viewers head (tracked with a tracking system). The user gets the impression of being immersed into an environment by viewing both the real world scene (as a real-time video) and the annotation (as an overlay with graphical augmentations of the scene) on a small display placed in front of his eyes. Optical see-through AR displays avoid the use of real-time video to present the scene, but superimpose the real world with annotations that are displayed with projections using mirrors and/or semi transparent glasses. Yet another option are retinal scanning displays or virtual retinal displays [38], where a low power laser projects the scene augmentation directly onto the spectators retina. According to [2] "there is still no see-through display that has sufficient brightness, resolution, field of view, and contrast to seamlessly blend a wide range of real and virtual imagery". Above that, for smart environment inspection the limited fidelity as imposed by the HMD precludes user acceptance beyond occasional use. We therefore decided to avoid any approach involving an HMD, but instead build on holographic see-through technology.

With DigiScope, the user is handling a holographic display tablet just like a 6DOF window that opens a view into the virtual world. The tablet is an optical see-though display which allows for a very natural viewing and scene inspection. To implement correct views into the scene, the angle and perspective of the DigiScope is being tracked, instead of tracking the position and orientation of the user. Thus the user is freed from any system hardware obstacles like HMDs, stereoscopic glasses, trackers, sensors, markers, tags, pointers and the such. DigiScope builds on hologram technology manufactured in a thin film and laminated to a transparent acrylic plate. The film responds to light rear projected in an angle from 30°-35° and is very selective about the direction of the arriving light: ambient light or even sunlight is ignored, black images appear transparent on the DigiScope. This allows to implement any scene annotation as a non-black overlay projected onto the DigiScope. To support free navigation in the secen, the DigiScope can be fully tilt and rotated in space by hand. The projecting beamer is fixed in the right projecting angle within a 6DOF mounting frame (Figure 1), and is used to project the computer generated image encoding the scene annotation. For tracking the position and orientation of the DigiScope frame, an Intersense IS-900 (www.isense.com) is used. The mounting frame also holds also a video camera (Sony DFW-X700) for optical marker recognition and a touchpad for user interactions.

The DigiScope software architecture is based on standard building blocks for AR application frameworks: (i) a 6 DOF tracking library for position and orientation tracking of the DigiScope frame, (ii) Java and Java3D for 3D scene modelling, rendering and implementing user interaction, and (iii) the ARToolkit (www.hitl.washington.edu) for visual object tracking and scene recognition. For visual object recognition based on optical markers the JARToolkit package (www.c-lab.de/jartoolkit), a Java wrapper class for the ARToolkit, has been used.

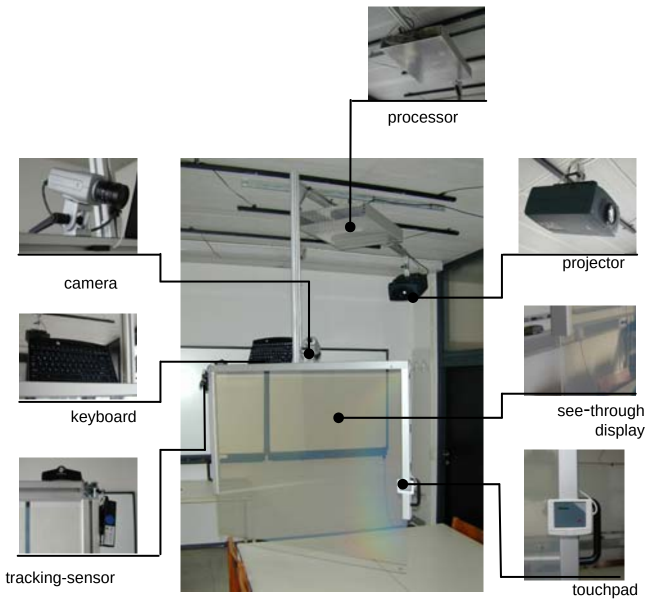

Fig. 1. DigiScope frame with details of the integrated components

In the current implementation, for the objects in a smart environment we distinguish (i) static objects which are not being (visually) tracked at runtime, but have a more or less static position in the scene, and (ii) dynamic objects, tagged with optical markers, tracked in position and orientation at runtime.

For scenes with an arbitrary number of static and dynamic objects, the DigiScope software frameworks creates visual presentations of predefined object annotations together with their corresponding hyperlinks into a 3D scene, which is in turn rendered by the Java3D engine and displayed (projected) onto the holo-screen. Object annotations can be any Java3D node, ranging from plain text to simple and very complex geometry, together with complex appearance attributes (e.g. for color, light, texture, etc.), and can exhibit arbitrary interpolator behaviours. The scene is rendered so as to give a true perspective view from the assumed position of the observers eye. Annotations are rendered perpendicular to the viewer, and Web-linking from within the scenegraph allows to use any information on the WWW for object annotation, and to access it during inspection. An apparent digital annotation of real world objects is the visual impression delivered to the viewer.

4 Inspecting the SmartCase with DigiScope

A context aware smart appliance [13], SmartCase, has been developed to illustrate a contextware software framework [11]. The hardware for the SmartCase demonstration prototype uses an embedded single board computer integrated into an off-the-shelf suitcase (Figure 2), which executes a standard TCP/IP stack and HTTP server, accepting requests wirelessly over an integrated IEEE802.11b WLAN adaptor. A miniaturized RFID reader is connected to the serial port of the server machine, an RFID antenna is integrated in the frame of the suitcase so as to enable the server to sense RFID tags contained in the SmartCase. A vast of 125KHz and 13,56 MHz magnetic coupled transponders are used to tag real world objects (like shirts, keys, PDAs or even printed paper) to be potentially carried (and sensed) by the suitcase. The SmartCase itself is tagged and possibly sensed by readers integrated into home furniture, car or airplane trunks, conveyor belts etc., so as to allow for an identification and localization at any meaningful point in space of the application. In addition, the SmartCase is equipped with optical markers so as to enable visual recognition and tracking with the ARToolkit framework.

Within the contextware software framework [11], an application specific abstraction of the real world is generated from three generic classes for persons, things, and places [21]. The reification of physical world objects and their relation among each other is expressed in RDF [18]. The person object represents the concepts about a person that are necessary to link their physical properties and activities to the virtual world. The thing object encapsulates the basic abstraction for objects relevant to the application and has instances like shirt, bag, etc. The place object is used to represent the essential features of a physical location like an office room or a waiting lounge. Places, things and persons may be related in a manifold of ways. The contextual interrelatedness among those object instances is expressed by a set of (bilateral) object relations within the resource description framework (RDF). Real world scenarios – like the situation of the SmartCase – are expressed as RDF statements, i.e. denoted as subject, predicate and object triples. A subject in RDF is represented by a resource, that could be a URL, a simple HTML file, a URI reference etc., a predicate is represented by a property describing a resource or the relation among resources, and an object is represented by a property value. To represent state changes in the real world, a set of sensors (like the RFID reader embedded into the frame of the SmartCase) are used to dynamically modify a set of relations that hold among the corresponding RDF resources at runtime. Such relations are for example the `owns` relation to expresses ownership of a real world object by another, the `contains` and `is_in` relations to expresses geometrical containment of an object within another one, the `contained` and `was_in` relations trace the history of containment etc.

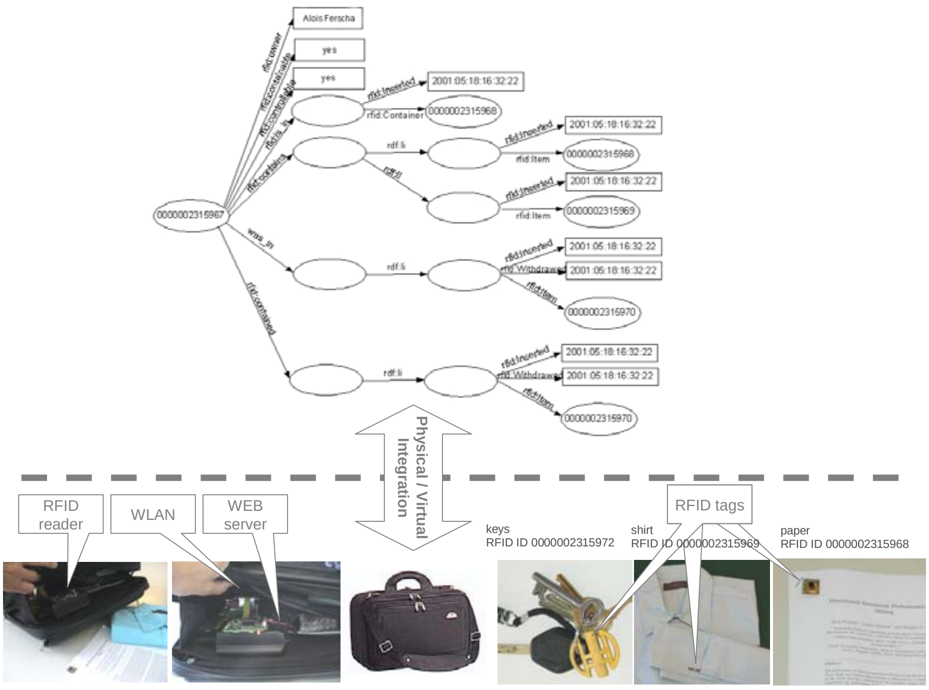

Fig. 2. Physical Virtual World Integration

A unique ID associated with every real world object is the ID encoded in its RFID tag. It is sensed by the RFID reader which triggers a script to update the involved object RDFs (Inserting e.g. the shirt into the suitcase would cause the RFID reader to identify the shirt tag and automatically update (among others) both the shirts RDF relation `is_in`, as well as the suitcases RDF relation `contains` by cross-referring URIs. Considering now the `contains` relation of the object SmartCase as an "invisible" inventory service, then, once an object (e.g. shirt) has been put into the SmartCase, this service can be queried to check whether the shirt is in the case or not. A straightforward way to access this information would be via a classical http interface to the embedded web-server. Observed via the DigiSpace however, changes to the SmartCase inventory – or in other words: the `contains` relation – are displayed as a graphical annotation of the real world.

Figure 3 illustrates a sequence of user interactions with objects in the real world and the corresponding state changes in the augmented world representation as seen through the DigiScope. In (1) the SmartCase is shown, annotated with the hyperlink “SmartCase” on the DigiScope display. A shirt is put into the SmartCase (2). RFID sensors detect the presence of the shirt and immediately after the digital counterpart of the shirt is shown as content of the SmartCase on the DigiScope (3). Similarly, the action of putting a paper document into the SmartCase (4) is detected by the system and consequently a hyperlink (Web link) to the paper appears on the DigiScope display (5). After adding further items (PDA, shown in 6 and 7, and a bunch of keys, 8 and 9), annotations for all objects are visible and manipulable via the DigiScope.

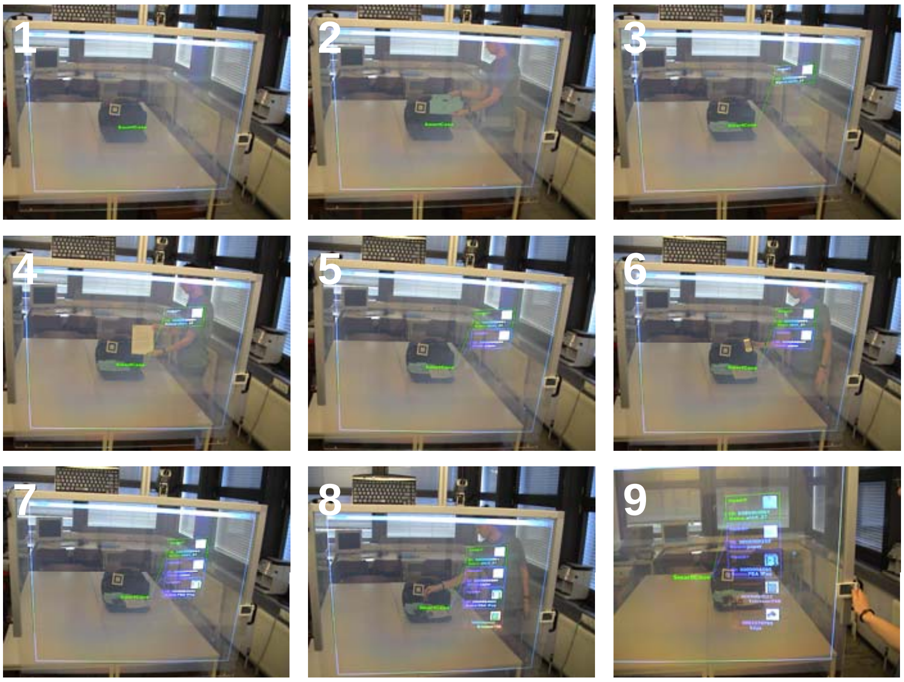

Fig. 4 Inspecting the SmartCase Packing Process

A major feature of the DigiScope hyperlink annotation concept when accessing “hidden” services in a ubiquitous computing landscape is the seamless access to the WWW. Figure 4 illustrates how the inventory of the packed SmartCase (1) is accessed via the URL links associated with each item in the inventory list. In (2), the user views all the content of the SmartCase. He is interested in the paper document (item 2 in the list), and thus navigates the cursor to the URL link in the annotation and clicks on it (3). This event is captured by the DigiScope and as a response, a Web browser is spawned displaying html related to the paper ID, which contains a Web link to the pdf document itself. Browsing this link spawns a pdf viewer allowing to interact with the digital counterpart of the physical document in the usual manner.

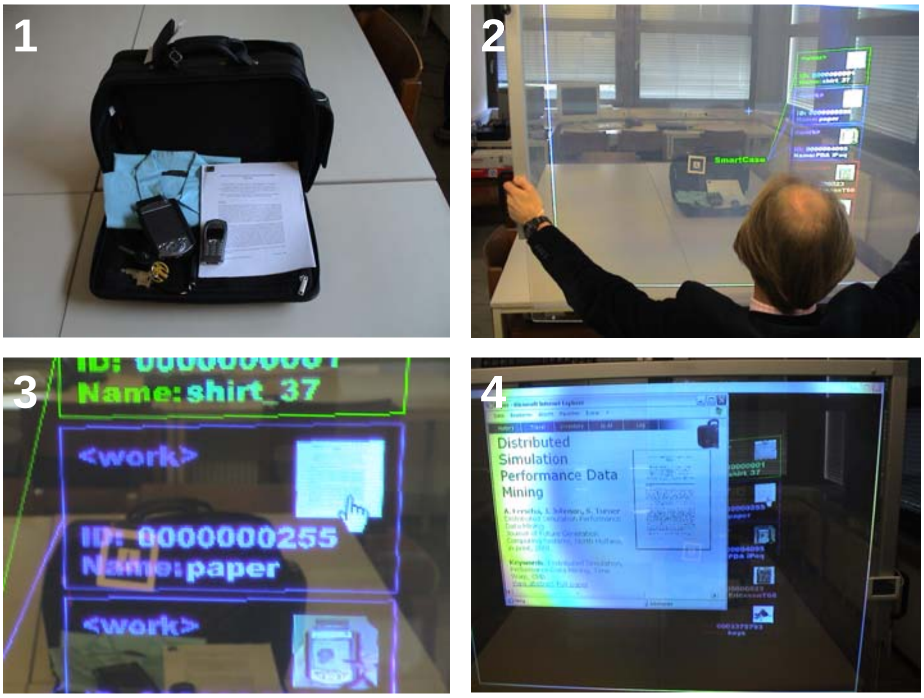

Fig. 4 Inspecting the SmartCase Inventory / Accessing Hidden Services

5 Conclusion

A shift form the "one person with one computer" paradigm has been induced by the ubiquitous computing (Weiser) and augmented reality (Wellner) vision. Networked embedded systems have gained from the technological progress in sub-micron and system-on-a-chip designs, novel wireless communication technologies, and the miniaturization of multisensor and actuator systems – and have started to populate our environment in a breathtaking way: everyday objects and architectural spaces equipped with networked embedded system technology have become "the interface" to an invisible, digital world of (computational) services. Embedded interfaces, however, pose radically new challenges to styles of interaction (situated interaction) and conceptual interface frameworks (tangible interfaces, attentive interfaces). To illustrate some of these challenges and to demonstrate our approach for the realization of embedded interactive systems we have presented prototypes of possible interfaces: SmartCase – a multisensor, wireless, embedded "carry-on" Internet appliance, and DigiScope – an intuitive interfaces for the perception and inspection of technology rich environments together with their "invisible" services. DigiScope envisions a new type of MR interface with two main features: (i) a new exploration experience of the physical world seamlessly merged with its digital annotations via a non-obtrusive MR interface, and (ii) an integration of ubiquitous context-awareness and physical hyperlinking at the user interface level.

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References

1. Anderson, D., Frankel, J.L., Marks, J.W., Agarwala, A., Beardsley, P.A., Hodgins, J.K., Leigh, D.L., Ryall, K., Sullivan, E., Yedidia, J.S.: Tangible Interactions and Graphical Interpretation: A New Approach to 3D Modeling. ACM SIGGRAPH (2000) 393-402
2. Azuma, R., Baillot, Y., Behringer, R., Feiner, St., Julier, S., MacIntyre, B.: Recent Advances in Augmented Reality. Computers&Graphics, Vol. 21 No. 6 (2001) 34-47
3. Benford, S., Schnadelbach, H., Koleva, B., Gaver, B., Schmidt, A., Boucher, A., Steed, A., Anastasi, R., Greenhalgh, C., Rodden, T., Gellersen, H-W.: Sensible, sensable and desirable: a framework for designing physical interfaces. Technical Report Equator-03-003, Equator, February (2003)
4. Billinghurst, M., Kato, H.: Collaborative Mixed Reality. Proc. ISMR99 (1999) 261-284
5. Bobrich, J., Otto, S.: Augmented Maps. IAPRS, Vol. 34 Part 4, Ottawa, Canada (2002)
6. Brown, B., MacColl, I., Chalmers, M., Galani, A., Randell, C., Steed, A.: Lessons from the lighthouse: Collaboration in a shared mixed reality system. In tbc, editor, Proceedings of CHI '2003, New York, January 2003. ACM Press, (2003) to appear
7. Cheok, A.D., Weihua, W., Yang, X., Prince, S., Wan, F.S., Billinghurst, M., Kato, H.: Interactive Theatre Experience in Embodied + Wearable Mixed Reality Space. ISMAR02 (2002) 59-68
8. Dey, A.K.: Understanding and Using Context. Personal and Ubiquitous Computing, Special Issue on Situated Interaction and Ubiquitous Computing, Vol. 5 No. 1 (2001)
9. Esler, M., Hightower, J., Anderson, T., Borriello, G.: Next Century Challenges: Data-Centric Networking for Invisible Computing: The Portolano Project at the University of Washington. Mobicom99 (1999) 256-262
10. Estrin, D., Culler, D., Pister, K., Sukhatme, G.: Connecting the Physical World with Pervasive Networks. Pervasive Computing, Vol. 1 No. 1 (2002) 59-69.
11. Ferscha, A.: Contextware: Bridging Virtual and Physical Worlds. Reliable Software Technologies, AE 2002. Lecture Notes in Computer Science LNCS 2361, Berlin (2002) 51-64
12. Garlan, D., Siewiorek, D., Smailagic, A., Steenkiste, P.: Project Aura: Towards Distraction-Free Pervasive Computing. IEEE Pervasive Computing, special issue on Integrated Pervasive Computing Environments, Vol 1, No 2 (2002) 22-31

13. Gellersen, H.W., Beigl, M., Schmidt, A.: Sensor-based Context-Awareness for Situated Computing, Proc. of Workshop on Software Engineering for Wearable and Pervasive Computing, Limerick, Ireland, June, (2000) 77-83
14. Gorbet, M.G., Orth, M., Ishii, M.: Triangles: Tangible Interface for Manipulation and Exploration of Digital Information Topography. Proc. CHI1998 (1998) 49-56
15. Intille, S.S.: Change Blind Information Display for Ubiquitous Computing Environments, UbiComp 2002, Lecture Notes in Computer Science 2498, Springer Verlag, Berlin, (2002) 91-106
16. Kindberg, T., Fox, A.: System Software for Ubiquitous Computing. IEEE Pervasive Computing, Vol. 1 No. 1 (2002) 70-81
17. Kitamura, Y., Itoh, Y., Masaki, T., Kishino, F.: ActiveCube: A Bi-directional User Interface using Cubes. KES2000, Conference on Knowledge-Based Intelligent Engineering Systems & Allied Technologies (2000) 99-102
18. Lassila, O., Swick, R.R.: Resource Description Framework (RDF): Model and Syntax Specification. Recommendation, World Wide Web Consortium (1999)
19. Liu, P., Georganas, N.D., Boulanger, P.: Designing Real-Time Vision Based Augmented Reality Environments for 3D Collaborative Applications. Proceedings of the IEEE Canadian Conference on Electrical & Computer Engineering (2002) 25-31
20. Ma, H., Paradiso, J.A.: The FindIT Flashlight: Responsive Tagging Based on Optically Triggered Microprocessor Wakeup, UbiComp 2002, Lecture Notes in Computer Science 2498, Springer Verlag, Berlin, (2002) 160-167
21. McGrath, R.E., Mickunas, D.E.: An Object-Oriented Framework for Smart Spaces. submitted to OOPSLA2001 (2001)
22. Milgram, P., Takemura, H., Utsumi, A., Kishino, F.: Augmented Reality: A class of displays on the reality-virtuality continuum. Proc. SPIE, Vol. 2351, Telemanipulator and Telepresence Technologies (1995) 282-292
23. Okuma, T., Kurata, T., Sakaue, K.: VizWear-3D: A Wearable 3-D Annotation System Based on 3-D Object Tracking using a Condensation Algorithm. IEEE Virtual Reality Conference 2002 (2002) 295-296
24. Poupyrev, I., Tan, D.S., Billinghurst, M., Kato, H., Regenbrecht, H., Tetsutani, N.: Developing a Generic Augmented Reality Interface. IEEE Computer Vol. 35 No. 3 (2002) 44-50
25. Piper, B., Ratti, C., Ishii, H.: Illuminating Clay: A 3-D Tangible Interface for Landscape Analysis. CHI2002 (2002) 355-362
26. Pradhan, S., Brignone, C., Cui, J-H., McReynolds, A., Smith, M.: Websigns: Hyperlinking Physical Locations to the Web. IEEE Computer, Vol. 34 No. 8 (2001) 42-48
27. Regenbrecht, H., Wagner, M.: Interaction in a Collaborative Augmented Reality Environment, CHli 2002 Extended Abstracts, (2002) 504-505
28. Rekimoto, J., Ayatsuka, Y.: CyberCode: Designing Augmented Reality Environments with Visual Tags. Proceedings of DARE2000 (2000) 1-10
29. Roman, M., Campbell, R.H. : GAIA: Enabling Active Spaces. In 9th ACM SIGOPS European Workshop (2000) 229-234
30. Römer, K., Schoch, T., Mattern, F., Dübendorfer, T.: Smart Identification Frameworks for Ubiquitous Computing Applications. Proceedings of PerCom 2003 (IEEE International Conference on Pervasive Computing and Communications), (2003)
31. Satyanarayanan, M.: Pervasive computing: Vision and challenges. IEEE Personal Communications, Vol. 8 (2001) 10-17
32. Schnädelbach. H., Koleva, B., Flintham, M., Fraser M., Izadi, S., Chandler, P., Foster, M., Benford, S., Greenhalgh, C. and Rodden, T., The Augurscope: A Mixed Reality Interface for Outdoors, in Proc. ACM Conference on Human Factors in Computing Systems (CHI 2002), 20 – 25 April 2002, Minneapolis, Minnesota, ACM Press, (2002) 9-16

33. Schnaider, M., Seibert, H., Schwald, B., Weller, T., Wesarg, S., Zogal, P.: Medarpa - Ein Augmented Reality System für Minimal-Invasive Interventionen. 2. Int. Statustagung Virtuelle und Erweiterte Realität, Leipzig (2002)
34. Schmidt, A.: Implicit Human-Computer Interaction trough Context, Personal Technologies 4(2 and 3), June, (2000) 191-199
35. Schmidt, A. Van Laerhoven, K: How to Build Smart Appliances?, IEEE Personal Communications 8(4), August, (2001) 66-71
36. Schwald, B., Seibert, F., Weller, T.: A Flexible Tracking Concept Applied to Medical Scenarios Using an AR Window. Poster at ISMAR2002 (2002)
37. Sousa, J.P., Garlan, D.: Aura: an Architectural Framework for User Mobility in Ubiquitous Computing Environments. Proceedings of the 3rd Working IEEE/IFIP Conference on Software Architecture (2002) 25-31
38. Viirre, E., Pryor, H., Nagata, S.: The Virtual Retinal Display: A New Technology for Virtual Reality and Augmented Vision in Medicine. In Proceedings of Medicine Meets Virtual Reality. San Diego, California, USA (1998) 252-257
39. Wand, F., Weiser, M., Mynatt, E.: Activating Everyday Objects. Proceedings of the 1998 DARPA/NIST Smart Spaces Workshop, Vol. 7 (1998) 140-143
40. P. Wellner, W. Mackay, R. Gold: Computer Augmented Environments: Back to the Real World. *CACM*, Vol. 36, No. 7, 1993.
41. Weiser, M.: The Computer of the Twenty-First Century. Scientific American (1991) 94-100