

Goal-Driven opportunistic Sensing

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ABSTRACT

Opportunistic activity and context recognition systems do not presume a static sensor infrastructure that is defined at the design time of a system. They also do not have a fixed recognition goal that has to be accomplished. These systems rather make best use of the available sensor systems according to a sensing mission whereas the topology of a sensor network may change at runtime. To being able to configure the available sensor systems and to react on topological changes in the ambient sensor infrastructure goal-oriented sensing approaches capable of handling dynamic sensor setups have to be developed within the authors PhD-thesis.

Author Keywords

Activity and Context Recognition, Goal-oriented Sensing, Wireless Sensor Networks, Goal Processing.

ACM Classification Keywords

I.0 Computing Methodologies: General.

General Terms

Algorithms, Design, Theory.

INTRODUCTION AND MOTIVATION

Activity and context recognition systems are an interesting research field in pervasive and ubiquitous computing [9]. By applying (wireless) sensor networks which deliver data of the physical world and the persons living and acting in it [11] such systems interpret the data in terms of inferring activities and more generally the context [1, 2, 7] of persons and subjects in real world environments. Examples for activity- and context recognition systems can be found in different domains, like industrial [15] or health-care applications [16].

Context and activity recognition can be split in the following two different rough sequenced steps [14]:

- Sensor signal acquisition by applying physical, logical and virtual sensor devices [10]. This step can be assigned to

the general areas of (wireless) sensor networks (WSN) [11, 18] and mobile ad-hoc networks (MANET) [19].

- Classification of the achieved data into a set of output classes, which describe activities and the context. This step includes data preprocessing, data segmentation, feature extraction, pattern recognition, etc.

All such activity and context recognition systems have shared one major problem so far: the sensor deployment and the recognition goal are application specific and thus the mapping from sensor signals to context and activities has to be known and defined at *design time* [13, 14]. This results in a static and predefined sensor infrastructure and provides no flexibility in the sensor deployment and positions (e.g. body-worn sensors have to be placed *exactly* at predefined positions) or the sensors availability (e.g. sensors can fail due to various reasons). Sensor systems are nowadays getting smaller and smaller and due to their capability of communicating with wireless interfaces their mobility is increasing [4]. Due to this node-mobility on the one hand and the limited power resources resulting from the fact that the small and wireless devices are not permanently attached to a power socket [17] on the other hand, the infrastructure of a wireless sensor network can change permanently and cannot assure that a probably predefined sensor setup is static and stable over a certain amount of time.

The term *opportunistic* means that no predefined sensor infrastructure nor a recognition goal have to be defined at the design time, the system rather makes best use of the available sensor devices according to a high level recognition goal stated by a user and/or an application, whereas when the system once started to operate, this sensor-setup is also not presumed to be fixed. The system reacts on changes in the sensor network topology at *runtime*. For example, new sensor nodes can be added to a running system, or existing nodes may be disconnected (e.g. they may run out of power or due to their mobility move out of the range of the system). An opportunistic activity and context recognition system has to react properly at runtime to such dynamics and unpredictable changes in the sensor infrastructure to always have the best available sensor setup configured to meet the requirements of a recognition goal.

The rest of the paper is structured as follows. The next section contains a description of the general problem domain and the specific problem addressed. Furthermore, open re-

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search questions that shall be answered in the authors PhD-thesis are listed. The section *Results and Methodological Approach* describes the research activities and results that have been achieved so far, and a description of the methodological approach of how the research work will be done in the future. The last section provides a conclusion, an outlook to future work and an estimation of the expected contribution to the community when the thesis is finished.

PROBLEM DOMAIN AND RESEARCH CHALLENGES

As already mentioned, the main differences between conventional and established activity and context recognition systems to opportunistic systems are the absence of a pre-defined static sensor infrastructure and the ability of goal-oriented cooperative sensing according to a user/application stated high-level goal. Figure 1 (on the left hand side) shows the general methodology of "conventional" activity and context recognition systems, where a defined set of sensors delivers data. By applying fixed algorithms for multi-sensor fusion and pattern recognition such systems are not flexible according to changes in the sensor infrastructure or by being able to execute dynamically defined goals. Examples for such systems and frameworks can be found in [6], [5] and more general in [2]. On the right hand side of figure 1 the goal (also referred to as sensing mission) defines the requirements for the sensors. An opportunistic system configures the currently best available set of sensors according to the recognition goal. This ensemble then delivers real world environmental data to the system/application (illustrated in figure 1 as dashed line).

The research challenges in opportunistic activity and context recognition systems are very widespread. They reach from energy optimization in wireless sensor networks, communication and routing issues between the sensor nodes, general methodologies on cooperative goal oriented sensing to appropriate processing of the delivered sensor data and the computer-based interpretation of this data to generate useful information (e.g. activities and context of users). As this paper is a summarization of the authors main research interests which build the base for a PhD-thesis, only one specific area in the field of opportunistic activity and context recognition can be picked and further explained: *goal-driven opportunistic sensing*.

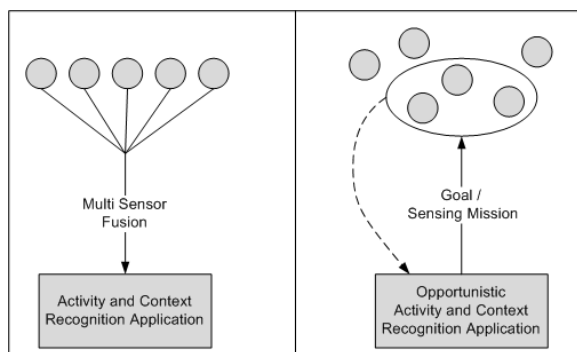


Figure 1. A conventional activity and context recognition system (left hand side) versus an opportunistic system (right hand side).

This area of research challenges deals with the problem, how a goal, which can be stated by a user or another application (which can be even another goal which is more high-level), has to be formulated in an abstract manner and further processed and translated by the system to enable goal-driven opportunistic sensing. This is different and a novelty in contrast to common activity and context recognition systems as their recognition goals are application specific and defined at design time. Appertaining to the formalism how a goal has to be stated on top level, the translation and representation of this goal into a machine readable form is an open question, as well. Therefore, goal representation languages and translation mechanism have to be ascertained. Based on this machine-readable goal representation, a coordinated sensing mission has to be built, which is used by the available sensor systems to self-organize and build cooperative ensembles that are best suited to execute this very sensing mission. Related research topics, that do not belong to the main topic of interest, but are also relevant and thus have to be mentioned in the paper and considered during research work are (i) cooperative sensing, (ii) self-description, self-organization and self-management (the *self-** capabilities) of sensor nodes [8], (iii) formation and configuration of coordinated sensor ensembles and the proper reaction to topological changes in the sensor infrastructure and/or the requirements of a goal and (iv) qualitative requirements like scalability, real-time processing, latency, response time, etc. The following subsection provides the open research questions in the field of goal formulation, goal processing and goal-driven sensing, that build the base for the authors PhD-thesis.

Research Questions

The following list summarizes the open research questions in the field of goal-driven opportunistic sensing that shall be answered within the authors thesis:

RQ1: How has a high-level recognition goal to be formulated by a user or application to be further processable by an opportunistic activity and context recognition system?

RQ1.1: Can a typology of goals be assessed and how can such a typology contribute to the goal-driven sensing process?

RQ1.2: How has a valid and satisfying result for a goal to be defined?

RQ1.3: Does a goal always have to be executable? If not, how can be decided to terminate a goal without any result?

RQ2: Which technologies are applicable for goal representation, composition and translation and how have these technologies to be defined and configured?

RQ3: How has the software representation (the machine-readable translation) of a recognition goal to be defined to meet the requirements for an opportunistic activity and context recognition system?

RQ4: How can a high-level recognition goal be translated to a machine readable representation? In which form is

knowledge-based processing necessary for goal translation and how has this to be defined?

RQ5: How can the machine readable translation of a recognition goal be applied by the sensor nodes and the system to configure the sensor ensemble that is best suitable to execute this goal/sensing mission?

RQ5.1: How has sensor self-description be defined to help configuring the sensors to ensembles according to a recognition goal?

RQ5.2: How and in which form can self-organization and self-management enabling technologies contribute to (i) the configuration of sensor ensembles according to a recognition goal and (ii) the reconfiguration due to topological changes in the sensor infrastructure (at runtime)?

RQ5.3: How can the contribution of a single sensor node to a given recognition goal/sensing mission be quantified at runtime of the system?

RQ5.4: How can the degree of fulfillment of an established sensing ensemble be calculated, quantified and optimized according to a given goal/sensing mission at runtime of the system.

RESULTS AND METHODOLOGICAL APPROACH

As this thesis directly contributes to the work of the European FP7 FET-open research project *OPPORTUNITY* (see <http://opportunity-project.eu/> and [13, 14]) and vice versa, good results have already been achieved so far. We have recorded and labeled a rich activity and context dataset in a kitchen scenario [12]. This dataset will build the base and ground truth for further experiments and research activities concerning goal-driven opportunistic sensing in an activity and context recognition system. Furthermore, a prototypical implementation of an opportunistic activity and context recognition system (referred to as the *OPPORTUNITY* framework) is currently being developed using OSGi (<http://www.osgi.org>), whereas the main focus so far lies on the abstract implementations of the sensor modalities used in the kitchen dataset. The main idea is to have software abstractions reproducing the behavior of the physical sensor systems that were used in the scenario that can be easily used for simulations. We have recorded real environmental data in the kitchen with real physical sensors and the software simulating these sensors provides these prerecorded data streams in real time. Figure 2 shows the graphical visualization of the software simulations using an implementation of the OSGi service specification *wire admin* of the magnetic reed switches used in the kitchen dataset on different objects (see [12] for further details) and the data flow of the (recorded) data in real time to a simple sensing mission (the red rectangle in Figure 2).

Furthermore, we have already assessed the sensor self descriptions, whereas it is segmented into a technical part and a goal-driven/opportunistic related part. Figure 3 shows the different types of self-description in the system. The technical part follows a well established standard (e.g. SensorML [3]). The dynamic and goal-driven related part describes (i)

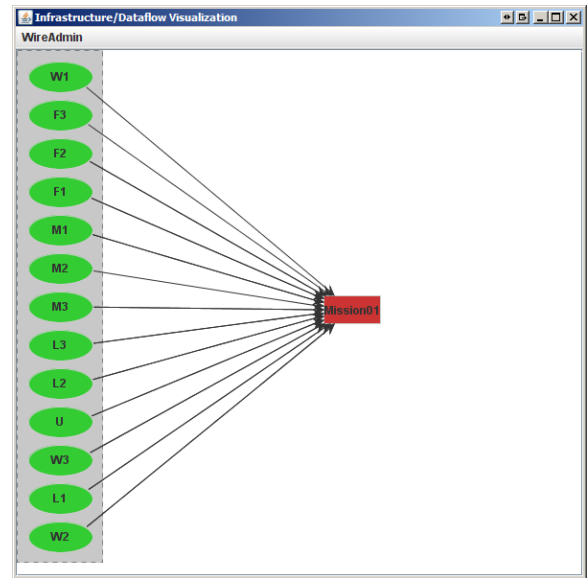


Figure 2. Graphical visualization of sensor nodes in the prototypical implementation of the *OPPORTUNITY* framework.

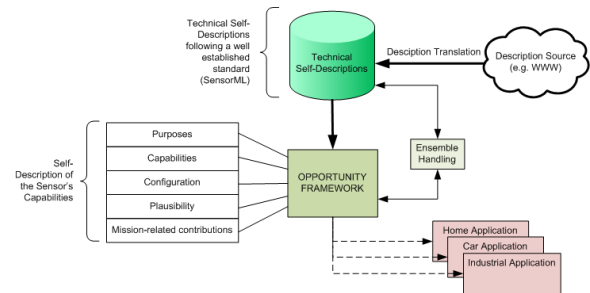


Figure 3. Self-description segmentation in the opportunistic system.

the sensors purposes (*what the sensor can do*), (ii) its capabilities (*how well the sensor is capable of something*), (iii) configuration details that might be needed to use the sensor in an ensemble, (iv) a self-awareness indicator defining the plausibility of the delivered data (the sensor is aware if it delivers malformed and/or senseless data) and (v) a mission/goal related indicator defining how well a sensor node contributed to a past sensing mission. By using the *OPPORTUNITY* framework the evolved techniques and methodologies shall be tested and evaluated. Therefore, two exemplary cases that will be taken from the kitchen scenario build the empirical testing part of the thesis. Main goal for the thesis is to answer the research questions.

CONCLUSION AND FUTURE WORK

Within this paper we have shown the differences between conventional activity and context recognition systems and an opportunistic approach. As the sensor infrastructure is not predefined and fixed but dynamic and changes frequently in opportunistic systems, this area arises several interesting research challenges and open questions, whereas the main interest of the author lies in the topic of goal-driven sensing.

Therefore a battery of research questions, that build the base for the authors PhD-thesis has been listed.

Besides the analysis of different existing approaches, the main contribution of this PhD-thesis will be the development of methodologies and techniques that try to sufficiently answer the research questions by enabling goal-driven opportunistic sensing in an activity and context recognition system. A prototype system will be built (the *OPPORTUNITY Framework*) which will be used for evaluation and testing of the evolved methodologies and techniques.

The main contribution to the scientific community will be to develop new knowledge regarding goal-driven opportunistic sensing by evolving algorithms, methods and techniques and to evaluate and test them. The author's PhD-thesis could be the first step towards being able to build opportunistic activity and context recognition applications for different domains (e.g. smart homes, driver assistance systems, industrial applications, etc.).

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Biographical Sketch



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