Ubiquitous Computing by Utilizing Semantic Interoperability with Item-Level Object Identification

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Abstract. This paper presents a novel approach for utilizing item-level object identification in ubiquitous computing environment where the interaction between devices is based on semantic information interoperability. The paper also presents novel methods for human-machine interaction. In our approach we give a unique identifier for objects in the environment and combine the knowledge of the object identity with information from other sources by utilizing semantic information interoperability. The approach utilizes Smart-M3 interoperability solution for sharing semantic information between heterogeneous devices and RFID-technology for identifying physical objects in the environment. In order to demonstrate the use item-level tagging with semantic interoperability we have implemented a Smart Greenhouse demonstrator that consists of several smart devices and tagged objects.

Keywords: Ubiquitous computing; object identification; Smart-M3; interoperability.

1 Introduction

Computers have already spread everywhere in the world, and current trend is moving from one computer to multiple computers for each person. In the future it is expected that there can be up to one thousand tiny computers per each person [1][2]. The recent trend of ubiquitous computing will also make these computers and embedded devices far more invisible and natural part of our everyday life, so that we will use computers without even thinking about it. In this paper we use the term smart object for these devices that are capable to interact with each other and with the physical environment without human assistance.

Our homes and working places are already full of various electronic devices which provide the user with heterogeneous user interfaces. In addition most of these devices don't have ability to utilize information of other device as effectively as possible. The vision of ubiquitous computing is to make our lives easier by providing us with meaningful services. In order to realize this vision, typical ubiquitous computing environment requires large amount of different kind of devices and applications that are capable to exchange information seamlessly and interpret the meaning of the

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information similarly. Achieving information level interoperability between heterogeneous devices can be challenging task however. Our approach to share information in ubiquitous computing environment is based on Smart-M3, which utilizes ontology-based information presentation and semantic web technologies to provide information-level interoperability for applications and devices in the environment. Smart-M3 functional architecture consists of two main entities: Knowledge Processor (KP) and Semantic Information Broker (SIB). SIB is the storage of ontology and provides interface for semantic information for the KPs. The actual smartness of the environment lies in KPs that perform meaningful actions according to the information fetched from the SIB. The interaction between the SIB and KPs is specified in Smart Space Access Protocol (SSAP).

In addition to exchanging information meaningfully, sensing the environment and the ability to interact with physical environment are key issues in ubiquitous computing. Therefore it is necessary to have an ability to identify physical objects and locations in order to enable meaningful interaction in with the environment. Radio-frequency identification (RFID) is one of the most popular methods to identify objects and it has been used in large variety of applications. Lately the price of RFID-tags has also decreased and this has made the technology even more tempting for smart space applications. RFID has been the enabler of automatic identification of tagged objects since the beginning of the smart space research. For example retail applications utilize universal item-level tagging, where every object is tagged with unique identifier (ID). Currently we have seen new kind of applications in the field of ubiquitous computing such as ubiquitous learning [3]. Data repositories provided by EPCglobal [4], uID [5] and others have enabled usage of this kind of universal item-level-based applications. However in local scale applications it is more feasible to use local database that is more suitable for storing the rapid changes in the environment such as states of actuators and locations of objects.

In this paper we will present how item-level object identification and semantic interoperability can be combined in a novel way to achieve new kind of methods for human-machine interaction and how smart objects can exploit the information about tagged items in Smart Greenhouse environment. In the proposed method we have given each object a unique ID, which can be read using mobile device with RFID-reader. The necessary information about the environment is stored in local information storage SIB that conveys the information to the smart objects in the space. That is how we can achieve semantic interoperability between devices and enable the devices to improve their behaviour according to information about tagged items.

2 Background

2.1 Ubiquitous Computing

The inventor of term “ubiquitous computing” Mark Weiser has written that “The most profound technologies are those that disappear. They weave themselves into the fabric of everyday life until they are indistinguishable from it” This sentence reminds the purpose of the ubiquitous computing, which is to make computers so invisible and natural to use that people can use them without thinking about it. Other similar terms for the vision behind ubiquitous computing are for instance pervasive computing, ambient intelligence and smart spaces. The key idea behind these terms is to achieve a technology that enables heterogeneous ubiquitous devices to communicate autonomously with each other in order to assist us in our everyday life. These ubiquitous devices can be divided to three groups:

- Sensors, which collect information about the environment, humans and other objects in space. Context-awareness is one the key issues ubiquitous computing.
- Actuators, which can make changes to environment.
- Processors, which read data and make decisions according that that data [6].

Even though devices can be divided to previous groups, many of real-life devices have some qualities of each of these groups. One example of ubiquitous device that has several qualities of previous groups is a mobile phone. Current mobile phones are already capable to sense the environment and make decisions according to that data, however, in order to exploit the true power of ubiquitous computing, different devices should be able to exchange information seamlessly with each other. In any case the mobile phones are probably the most interesting physical interface for ubiquitous computing environment [7].

2.2 Object Identification with RFID

One of the key issues in ubiquitous computing is how to identify objects, locations and people. RFID has been used in wide variety of applications to identify objects and it is considered to become one of the most pervasive computing technologies in history [8]. The basic idea behind RFID is marking items with tags, which contain transponder to send message to RFID-reader. Mostly this message is just an identification number, but additional information can be also stored to tags. Decreased prices of individual RFID-tags have enabled the usage of RFID-technology in novel applications such as retail business, for example. Basically RFID can be consider as an alternative for barcodes or other visual tags, but it also improves the functionality by enabling tag reading without visual contact, providing larger information density and also providing two-way communication ability [9].

Especially interesting subclass of object identification is item-level tagging, where objects and locations have unique ID. In the future printed electronics may also provide very low-cost passive RFID-tags, which could be used as a replacement of the barcodes [10]. This makes tagging individual objects with RFID financially reasonable. The best known examples of universal item-level tagging are EPCglobal and uID, where all objects are numbered uniquely and thereby physical objects can be connected to digital counterparts.

Figure 1 shows a simplified architecture of universal item-level tagging. Object is tagged uniquely with RFID and tag reader reads ID from tag attached to object. Digital counterpart for that object is stored in remote database, which can be accessed via internet using tag reader device. For example uID-architecture uses 128bit long unique ID number called ucode for every object and location. 128-bit ID can be assigned practically limitless amount of objects. This ucode is stored in a tag, which can be either RFID-type or optical type such as barcode. Basic operation of uID architecture in simplified manner is that handheld computer called Ubiquitous Communicator (UC) reads ucode tag and retrieves corresponding data from remote database. UC and uID-architecture have been developed in YRP Ubiquitous Networking Laboratory (Tokyo, Japan), whose chairman professor Ken Sakamura is one of the pioneers in ubiquitous computing.

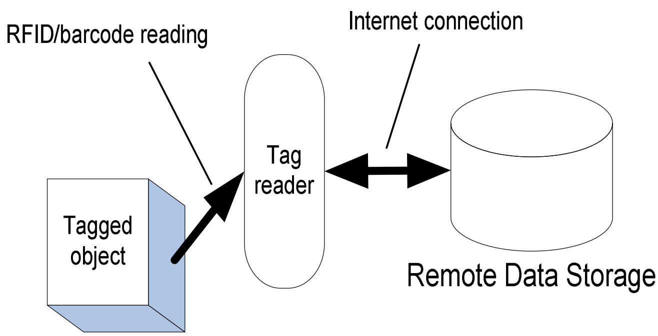

Fig. 1. Simplified architecture of universal item-level tagging

2.3 Semantic Interoperability and Smart-M3

The Semantic Web provides information level interoperability by presenting information as a collection of information called ontology [11]. It enables the computer applications to automatically interpret the meaning of the information and exploit it without human guidance. Several different technologies and design principles such as the Resource Description Framework (RDF), RDF Schema (RDFS), Web ontology language (OWL) and SPARQL have been developed in various Semantic Web working groups to enable information level interoperability between devices and humans. RDFS and OWL provides basic elements for describing ontologies and RDF is used to present ontologies in form of subject-predicate-object expressions, known as triples in RDF terminology. SPARQL is RDF query language and it is used to query RDF-type data.

Smart-M3 is an open source information level interoperability solution that can be implemented on top of any connectivity solution and it is device, domain and vendor independent [12]. It provides an architecture for sharing semantic information between software entities and devices. The information level interoperability in Smart-M3 is based on two core concepts: ontology-based information model and event-based functional architecture. The ontology-based information model of the Smart-M3 utilizes RDF and OWL technologies to present the information in ontology format. The Smart-M3 functional architecture defines how to access the shared information of the environment. Two main entities of the Smart-M3 functional architecture are KP and SIB. Figure 2 illustrates the core elements of Smart-M3 and their relations.

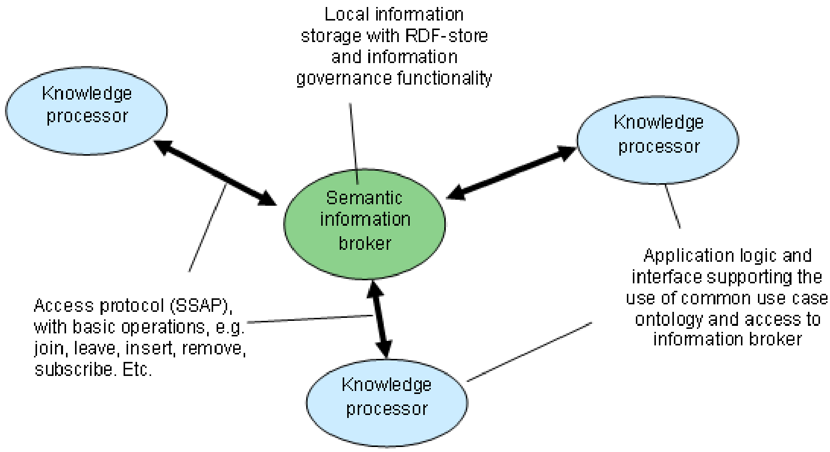

Fig. 2. Smart-M3 functional architecture

The Smart-M3 functional architecture is based on publish/query paradigm. SIB acts as a data repository, which stores semantic information as a RDF-type graph, which can be utilized by KPs. The actual smartness of the smart space lies in KPs, which can make smart decisions according to information that can be received from SIB. SSAP is the communication protocol of the Smart-M3 and it defines the rules and syntax of the communication between SIBs and KPs. Protocol supports all basic operations to publish and query information in ubiquitous environment.

3 The Use of Item-Level Object Identification with Smart-M3

In this section we present, how item-level object identification can extend the possibilities of Smart-M3 –based ubiquitous computing environment. We will combine item-level object identification with Smart-M3 to achieve:

- more natural human-machine interaction
- easier development of user interfaces for simple devices
- increased awareness of the environment and objects in the environment

3.1 System Model

System with heterogeneous devices that can share information using Smart-M3 interoperability solution is presented in figure 3. Objects in the ubiquitous computing environment are tagged with unique ID, which can be used to interact with object. In this approach we are using uID-based structure for presenting IDs. This structure is presented in section II. Reason for selecting the ucode structure is the possibility to utilize remote uID-databases in future applications.

Information of the tagged objects is stored in SIB, which is local database for storing the information in RDF-format. This information can be inserted to SIB using local database KP, which reads local item database and inserts information about possible items or ubiquitous devices to the SIB. Another option is to use KP, which can read remote database, e.g. uID-database, and add required information to the local SIB. The usage of local database KP is the best suitable option for initializing information about ubiquitous devices such as actuators, sensors and processors to the SIB. Usually the status of the actuators and sensors are changing relatively quickly so it is reasonable to store this kind of information to local database that provides easier and faster methods for exchanging data via shared memory than remote databases. SIB provides KPs with straightforward methods to insert e.g. changed measurement result of the sensor to memory, so it is very natural to use it as a local database. The usage of remote database is more suitable for storing unchangeable information about items e.g. consumer products, food and plants.

Figure 3 contains all kinds of ubiquitous devices: actuators, sensors and processors, which all have their unique identifier. Besides these ubiquitous devices different locations and items in the smart space are assigned with unique identifier. KPs have to be implemented to every ubiquitous device in smart space in order to publish and query information in smart space. Because of the variety of different ubiquitous devices implementing KP can be challenging task, but utilizing ANSI-C based portable KP interface makes KP design simpler [13]. In our approach KPs utilize the SIB service to share information with each others. Tag reader is the mobile device with RFID communication capability and it also contains KP implementation with ability to publish and query information using SIB service. Figure 3 presents identifiers as a RFID, but it is also possible to use e.g. barcodes.

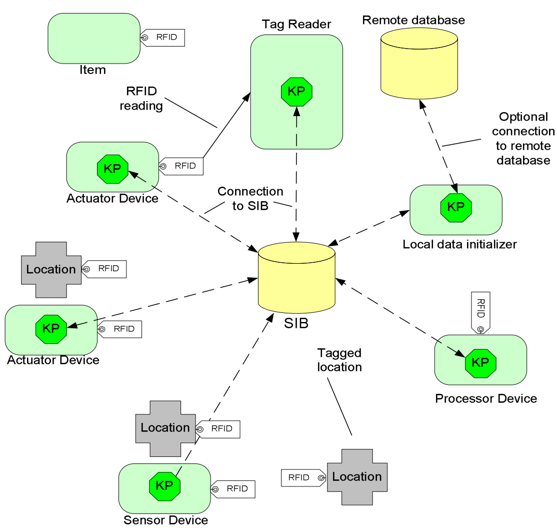

Fig. 3. Smart-M3 environment using item-level tagged objects

The basis of information presentation in the Smart-M3 information level interoperability solution is the usage of the ontologies. The most important task in implementing Smart-M3 –based ubiquitous computing environment is to design common ontology and common data presentation format. Commonly accepted method for identify a name or resource on the Internet is a string of characters called Uniform Resource Identifier (URI), which is also exploited in OWL. In our approach we are using 128-bit unique identifiers as URIs that can be used to identify objects in smart space. This method decreases the amount of memory needed to store the information of the objects in SIB compared to method that uses separate URI and unique identifier. Figure 4 shows RDF graph of example ontology related to ubiquitous devices, where unique identifiers such as id$_0$ are inserted in ontology in order to act as URIs. Each of these unique identifiers represent individual object: actuators, sensors, processors and items. The class of instance has been presented using type-indicator.

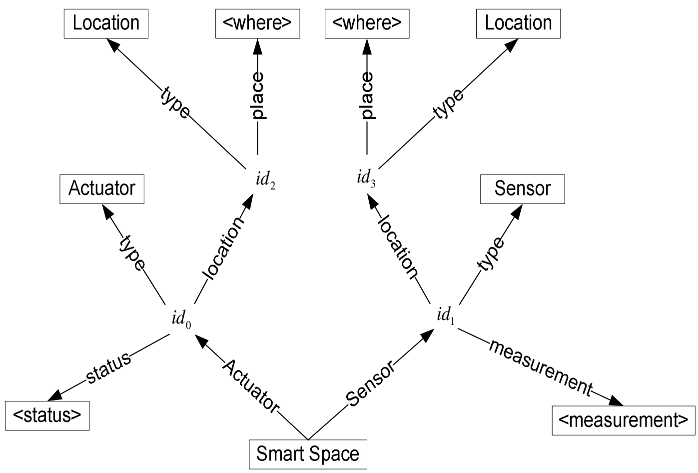

Fig. 4. RDF-graph of smart space with tagged items

3.2 Novel Applications Using Combined Item-Level Object Identification and Smart-M3

Identifying every object in ubiquitous computing environment with unique identifier brings novel approaches to interaction with objects. Mobile phones are expected to become to most important physical interface for ubiquitous computing environment so it would be very natural to use single mobile device with tag reader to control every ubiquitous device in the environment [14]. The same single device can be utilized also for viewing state information of the environment, which is produced by different sensors such as temperature-, humidity-, acceleration- and GPS-sensor.

Activating some function with mobile phone by selecting physical tag is an interesting vision for human-machine interaction [15]. Very clear examples of utilizing this idea are changing the status of an actuator, reading the measurements of the sensor or receiving information about item by touching these objects. Many simple ubiquitous devices can be controlled very similar ways, for instance basic operations for simple actuators such as air conditioner, heaters and lights are usually almost identical: they can be turned on or off and their level can be adjusted. Also many sensors produce very similar kinds of results, which usually include the measurement value and unit. Utilizing these similarities we can build harmonized user interfaces for mobile device that acts as a physical interface for ubiquitous computing environment. That is how we can control different kinds of actuators very similar way, which can improve usability significantly. If we can use our mobile phones as controllers and sensor readers, other devices can be made simpler and it is not necessary to incorporate expensive screens and buttons for every device.

Another example of using this approach is increasing the awareness of the environment and objects in the environment by touching. User can e.g. insert new objects in the environment and change the location of objects by touching object and location tag. Information about new objects and their locations can be exploited by processors that can control actuators. Typical example is the greenhouse, where different kinds of plants need different kind of care. Using the knowledge about what kind of plants are inserted in greenhouse, processor can control actuators such as heaters and lights in different ways. This kind of approach provides also interesting possibilities for user to make configurable actions in smart space relatively easily. For example user could decide what happens if certain types of items are brought to certain location or what happens if certain location tag is touched.

In each of these cases, heterogeneous devices such as actuators, sensors and processors need to interpret exchanged information. Information can be for example the status of actuator, measurement of sensor or the location of object. Therefore Smart-M3 based semantic interoperability is suitable method for information exchanging. Using proposed approach each of these cases follows the same basic procedure: reading the unique identifier using RFID-reader, querying unique identifier related data such as type, status, measurement or location from SIB, showing this information on mobile devices screen and optionally inserting modified information such as status of the actuator to SIB. In our approach we can combine information from different sources including Internet, RFID-reader, sensors and actuators to same ontology and store the corresponding RDF-graph in SIB. That is how we can implement interesting Smart-M3 mash-up applications that utilize combined information from different sources.

4 Implementation

In order to demonstrate the usage item-level tagging with semantic interoperability we have used our Smart greenhouse demonstrator. Smart greenhouse consists of five smart objects and several different plants. Figure 5 presents five KPs in demonstration environment exchanging information using SIB as an information repository. Different plants have been tagged with RFID-tags and that is how unique ID has been given to each of the plants.

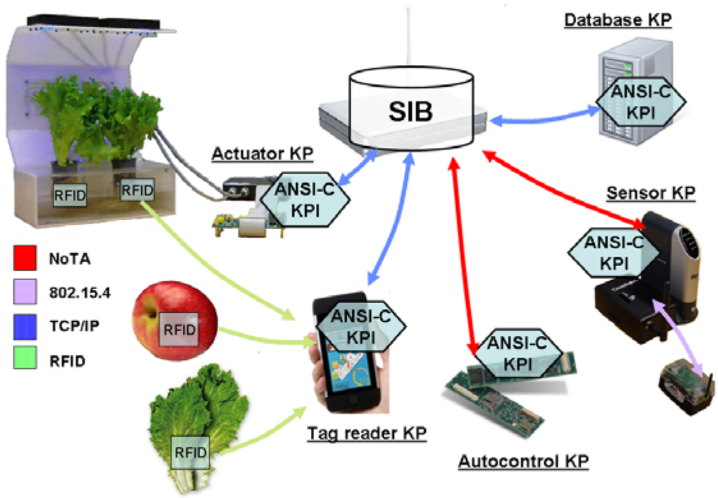

Fig. 5. Devices and plants in the Smart Greenhouse

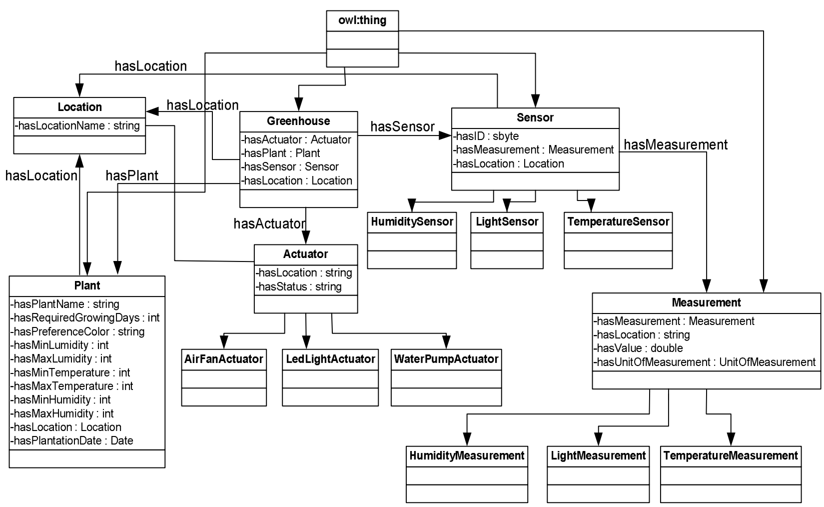

Fig. 6. Smart greenhouse ontology

In this demonstration case SIB is running in Asus WL500GPv1 Wireless Local Area Network (WLAN) access point (AP) with OpenWrt firmware. Demonstration environment has also five KPs for different purposes: Actuator KP for controlling greenhouse, Sensor KP for sensing the environment, Tag reader KP for detecting tagged objects, Database KP for initializing information about tagged objects to SIB and Autocontrol KP for controlling greenhouse when gardener is not present.

Smart greenhouse ontology is presented in figure 6. Plant, location, actuator, sensor, measurement and greenhouse are the main entities in the ontology, which is modelled using OWL. Every possible plant locations have been tagged with RFID-tags and we have also tagged several plants with similar kind of tags. RFID-tags contain unique 128-bit IDs, which are stored on the ontology using method presented in figure 4 in section 3.

Information about tagged objects is inserted to SIB using Database KP. Currently only local database is used, but in the future it could be possible to combine local database with remote databases e.g. uID database. In our approach information about every tagged object is initialized to SIB beforehand. We have ported our ANSI-C – based KP interface to UC with T-Kernel OS and implemented Tag reader KP on top of that KP interface. UC uses Bluetooth connected RFID-reader for tag reading.

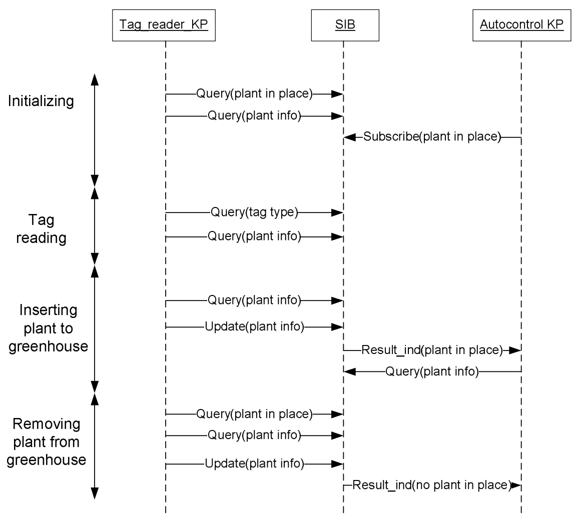

Fig. 7. Simplified sequential diagram of greenhouse activity

Figure 7 presents simplified diagram, how two different KPs operate in the greenhouse environment. Other KPs have been left off from the figure in order to clarify the case. At first the Tag Reader KP checks whether there are already some plants in the greenhouse and shows their information in the screen. Autocontrol KP also subscribes to the plants inserted to the greenhouse. When user touches uniquely tagged plant, Tag Reader KP first queries the type of the tag and then queries information related to that tag. User can also insert plants to greenhouse and in this case Tag Reader KP updates plant location to the SIB. When location is changed, Autocontrol KP gets indication about this event and queries plant information from the SIB. Each plant has different kind of preference conditions and Autocontrol KP tries to adjust temperature, humidity and light using these preferences that can be queried from the SIB. Autocontrol KP utilizes information about plants in the greenhouse and their preference conditions and compares these with current condition information produced by Sensor KP. If current conditions such as humidity, temperature and lumidity differ from plant preference conditions, Autocontrol KP updates new status for virtual actuator responsible for that environmental condition. The SIB then indicates Actuator KP about this event and Actuator KP can modify the corresponding physical actuator.

The results of using this approach in smart greenhouse environment showed the easiness to bring new information to environment by touching. Autocontrol KP is an example of application that can improve its behaviour using the knowledge of tagged objects in the smart space, in this case plants in the greenhouse. The same approach could be utilized in smart buildings, where devices adjust their behaviour to be more suitable for different persons. Smart-M3 provided efficient way to share information between smart objects and using semantic interoperability completely new smart space applications can be implemented rapidly. Because item-level information is stored in the ontology, it is very easy to utilize this information for different purposes.

5 Conclusions and Future Work

This paper presented an approach to use item-level tagging with Smart-M3 to produce novel method for interactions with tagged objects in ubiquitous computing environments. Our experiences obtained from the work were positive and by using semantic interoperability between different devices it was easy to bring new information to environment by touching. This approach makes also possible to reduce costs by offering possibility to make simpler devices without own screens and buttons. Item-level tagging can however cause performance issues to communication between KPs, because that kind of approach requires large amount of data to be inserted in SIB that can slow down the operation of the SIB. One solution for that problem could be the usage of external database, which inserts information to SIB only when needed.

As for future work, we are planning to test more detailed user interactions with different kind of sensors, actuators and other objects in ubiquitous computing environment. Moreover we are going to connect remote databases e.q. uID database to our demonstration environment in order to reduce the problems related to large amount of data inserted to SIB.

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