Today's Impact of Ubiquitous Computing on Business Processes

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Abstract. The aim of this paper is to show the impact of currently available ubiquitous computing technology on business processes. It shortly describes and investigates technologies, its drivers, and gives some examples of their application. This includes technologies like automatic identification, localization, and sensor technology that seem to have a strong impact on business processes. Building on these key technologies in ubiquitous computing, their impact on business processes is investigated. Firstly, business problems are stated, where the utilization of ubiquitous computing technology might provide a solution. Then, three application cases are presented to show the needs that drive the adoption of these technologies and to show how business processes are affected. A ubiquitous computing process model is proposed that is derived from the collection of cases. This model helps to identify application potentials for ubicomp computing technologies in a business environment. The paper closes with some future perspectives on ubiquitous computing applications.

1 Introduction

The vision of ubiquitous computing (ubicomp) is to seamlessly connect the physical world with its representation in information systems. A smart sickbed could be an example for such a connection, where patients in a hospital could benefit by the usage of ubicomp in several ways. The smart sickbed knows the patient who lies in it and his or her medical history. A physician can ask the sickbed for the medical history of the patient and can add his or her treatment. If the drugs, blood bottles or just the food arrives at the sickbed, it can check – using the medical history – whether theses items are compliant with the treatment for this patient. In the case that a wrong item should be given to the patient, the sickbed would notify the nurse.

Five trends show the technical feasibility of such solutions [1]. The first trend is given by Moore's law [2]. It states that the number of transistors on the same chip area doubles every eighteen months. Thus, the price and the size of computer chips are becoming so low that they can be integrated into everyday items. New materials denote the second trend. Smart paper [3] for example provides a new interaction scheme with IT systems: a thin and flexible plastic foil contains the electronic ink that can display information, but can also be used as an input device with a special pencil. Progress in communication technologies can be regarded as the third trend: besides the higher bandwidth, mobile networks, like the mobile phone network or new concepts like body area networks, where the body is used as transmission medium, give rise to new application types. A steering wheel could automatically identify and authenticate the driver, when he or she touches it. Progress in sensor technology is the fourth trend: sensors just like computer chips are getting smaller and cheaper, so that they can be integrated into everyday items to observe the environment. A milk bottle could calculate its expiry date depending on its current temperature: the colder the milk bottle, the later the expiry date. The last trend refers to new concepts that model the infrastructure for such smart everyday items.

Many new applications can be implemented having these five trends in mind. For example, an umbrella can check the weather service and remind its owner not to forget it, if it is likely to rain. An automatic inventory service can be implemented if every part in a warehouse sends a notification to the warehouse management system if it enters or leaves the warehouse.

Some examples may seem to be visionary, whereas others are more realistic and can already be implemented today. Companies that conduct a cost-benefit analysis may realize that some examples are profitable, whereas some are not. An automatic inventory solution could be an application that may be implemented today and may be profitable, too. In contrast, it might be problematic to build a profitable smart umbrella.

In this paper, the focus is on profitable and realistic examples, since such examples are the foundation for an economic investigation. At the end of this paper, however, we also look at more visionary examples. This paper shows which business processes are affected and how they are affected by ubicomp technology. Building on a collection of application cases, which rely on ubicomp technology, a ubicomp process model is proposed that describes a composition of business processes in order to identify application potentials.

The remainder of this paper is structured as follows. Section 2 investigates the most important ubicomp aspects that are relevant to the improvement of business processes. Building on that, section 3 shows the impact of these technologies on business processes and introduces a ubicomp process model. Section 4 closes with a summary how ubicomp technologies are used in a business environment today. It also provides a prospective how the impact of ubicomp technology on business processes may develop in the future.

2 Enabling Ubiquitous Computing Technologies

This section takes a closer look at some ubiquitous technologies that are important building blocks for commercial applications and their business processes. Building on the technical foundations, the implications of ubicomp on business processes are discussed in the subsequent section.

Currently, it seems that three ubicomp technologies have a direct and strong impact on business processes. Automatic identification, localization, and sensor technology provide the means to answer questions like: “Where is which product, what is its current state and what products are in its neighbourhood?”. Using this information, a drug can check if it has reached the expiration date, if it is compliant with the drugs in its neighbourhood and it can remind the patient to take in the pills. Another example is a spare part, which knows its position within the supply chain. In the following, the underlying technologies will be described from a technical point of view.

2.1 Automatic Identification

Automatic identification (Auto-ID) [4], [5] is a technology that is commonly used to identify products or delivery units. Typical Auto-ID systems are barcode, RFID, smart card, and biometric systems. Two tasks are common in the identification process for every Auto-ID system: capturing an external signal from the entity that should be identified (e.g. capturing the image of a barcode) and recognizing that signal by a computer analysis (e.g. retrieving the encoded information).

Barcode systems [6] are currently used throughout all industries in the world and can be regarded as the most important Auto-ID technology for object recognition. Every sector has its own barcode standards, like the Universal Product Code or the European Article Number Code for the retail domain. A typical barcode on a product can store data in the order of magnitude of some 10 bytes. Newer two-dimensional barcodes can store data in the order of magnitude of some 1000 bytes.

In Radio Frequency Identification (RFID) systems [7], small chips (tags) are attached to entities that store the identifier. An antenna is connected to the chip so that if the tag is within the read range of an RFID reader, the identifier can be read out without the need of line of sight. Active solutions have their own energy supply integrated into the tag, which enables them to transmit their identifier up to 100m. In contrast, passive solutions are typically able to transmit their identifier up to 2m. The emerging RFID systems are a good alternative to barcode systems, since they do not need human intervention and do not need line of sight between the tag and the reader. Machine vision, another Auto-ID technology, which derives the identity of an object by its image, and biometric systems for the recognition of humans can be expected to be important in future applications, after their reliability has been increased.

2.2 Localization

In the majority of cases, localization [8] is combined with automatic identification, since the sole location information is often useless without the identity of the located entity. Proximity is a simple localization technique, where wireless and cellular access points are monitored. If an entity can be recognized within a cell, such a system can determine that the entity must be in the proximity of the known position of the monitoring device. Proximity can also be derived from other Auto-ID systems, like smart card readers: if a smart card has been recognized and the position of the smart card reader is known, then it can be deduced that the owner of the smart card must have been at this position.

Lateration and angulation of RF or ultrasonic signals [9] are another frequently used localization techniques. Both techniques rely on distance or angle measurements between some fixed points. The measurement of signal propagation delays can be used to determine the distance. Attentuation uses the effect that the signal strength decreases depending on the distance, but the measurement of signal strengths to derive the distance is less precise than the commonly used lateration technique.

A third localization technique is scene analysis, which extracts features from the environment, like image data or signal strengths and compares these data to stored patterns in a database to derive the location of the entity. Compared to the other localization techniques, this one is currently less precise.

The raw location data is useless unless a location model [10] describes how the location of an object is related to the location of other objects and the environment. One type of location models uses coordinates and set of coordinates to describe the location. Euclidian distances can easily be computed in such models. Another type of location models comprises geographic and symbolic models, which are easily readable by humans, but not efficient processable by computers. Currently, a challenge is to combine these two types of models into semi-symbolic models: geometric models for efficient processing and symbolic models for human readability.

The Global Positioning System (GPS) is the only system that is widely in use today. It uses the lateration technique with one GPS receiver and 4 visible GPS satellites. A limitation is that it can only be used outdoors. Some indoor positioning systems have been proposed that use proximity or lateration with the signal propagation delay of ultrasonic and electromagnetic waves.

2.3 Sensor Technology

Different sensor types include thermal, acoustic, visual, infrared, magnetic, seismic or radar sensors to monitor conditions like temperature, humidity, vehicular movement, lightning conditions, pressure, soil makeup, noise levels, the presence or absence of certain kinds of objects, mechanical stress levels on attached objects or current characteristics such as speed, direction, and size of an object. Technical advances in MEMS (micro electro mechanical systems), which deals with machines in the nanometre scale, also influences the design of new sensors that are getting smaller in size and consume less energy.

Current research in sensor technology focuses on a broader issue: wireless sensor networks [11]. The innovations are the networking capabilities of sensors, which allow the network to benefit from being autonomous since they are no longer directly connected to a central controlling computer, from utilization in remote and unknown regions, and from synergy effects through collaboration.

2.4 Other Aspects in Ubiquitous Computing

Besides the three technologies mentioned above, some other research areas are important to enable ubicomp applications. Middleware, infrastructure, communication issues, privacy and security, and energy consumption are already in the focus of current research, e.g. in the field of distributed systems and mobile computing, but every field poses new questions in the ubicomp domain.

For example, privacy [12] and security [13] issues are even more important in ubicomp scenarios than in the Internet domain. Compared to the Internet, ubicomp applications bring in new aspects in quantity and quality. Potentially, there exist more products than computers and the data exchange refers to physical products. Solutions that have already been proposed for the Internet domain have to be adapted for the utilization in the ubicomp domain. Security topics try to secure communication links concerning confidentiality, integrity, and authenticity. Security aspects also include authorization, accountability, and non-repudiation. In contrast, privacy can be described as the claim of an individual to control the process of information collection, storage, processing and dissemination concerning his or her personal information. Anonymity of the users and keeping the processing of the users' data transparent for them are approaches that deal with this issue.

Currently, only a few ubicomp applications are available and they do not share a common infrastructure or middleware. Much research in every aspect of ubicomp has to be carried out to provide a common infrastructure and middleware for ubicomp applications.

3 Business Potentials of Ubiquitous Computing

The previous section summarized the technical aspects of ubiquitous computing. Building on that, this section investigates how these technologies can have an impact on business processes. First, some business problems are stated that can potentially be solved or improved with ubicomp technology. Then, business impacts are discussed if ubicomp technology is used. Three example applications show how ubicomp technology is already in use. In the end, a ubicomp process model is proposed, building on the previous results. This model identifies tasks where ubicomp can have an impact.

3.1 Business Problems

Most enterprises face a permanent need for innovation to be successful. New technologies can be used for competitive advantage and enable new products and services. There are still many problems that cannot be solved sufficiently with traditional IT systems like Enterprise Resource Planning (ERP) or e-business systems. Media breaks, human errors, and delayed information are the main reasons for inefficiencies in the information flow of enterprises. Below, some of these problems are stated.

Companies experience several problems related to their supply chains. According to A.T. Kearney, supply chain inefficiencies can waste up to 25 percent of a company's operating cost [14]. The insufficient coordination between material flow and information flow leads to the so-called bull-whip-effect [15]. Consequences are excess production or stock outs. For this reason, the majority of companies maintain costly safety stocks.

For the transport of goods, different transport units are used. Many of them are reusable, e.g. containers, crates, pallets, etc. The utilisation of such resources tends to be inefficient without active management. Searching for misrouted or misplaced goods is time-consuming without locating systems. In complex inventories, misplaced goods will be only discovered during stocktaking, which leads to "dead inventory". The handling of perishable or dangerous goods, e.g. blood bottles or chemicals, requires special precautions. Wrong temperatures or pressure conditions can lead to damage of goods.

Errors in production become expensive if they are not identified immediately. This can occur if monitoring and documentation of the production process is insufficient. In the case of recalls, affected goods often cannot be identified, because individual information on item basis is missing. In most cases, it is impossible or difficult to uniquely identify products. This facilitates theft and counterfeiting. Typically, affected products are CDs, electronics, spare parts, or razor blades, among others.

This list of business problems could easily be extended. Ubicomp technologies, like automatic identification, localization, and sensor technology are potential candidates to overcome these problems.

3.2 Business Impacts of Ubiquitous Computing

When companies plan to adopt a new technology, they want to know the business impacts in advance. These impacts are mainly characterized by benefits and cost. The source for the benefits can be described in a general way. In the field of ubicomp, sources for benefits are the avoidance of media breaks between the real world and the digital world, the awareness of "smart objects", and the support for mobility (Figure 1).

The avoidance of media breaks bears the potential to improve the efficiency of business processes through automation. A high level of process automation leads to reduced cost since less human intervention is required and human errors are eliminated. Awareness means that objects are able to provide data about their current and past context. Decisions that affect the object can be made at the object itself.

For example, a blood bottle can decide whether it is stored always at the right temperature. It can be asked whether it was kept at the right temperature. In a traditional process it must be ensured that thermometers are always around for external monitoring. These thermometers must be checked manually every time the blood bottle changes its location. This process is laborious, error-prone, and does not provide an appropriate means to measure the actual quality of the blood bottle.

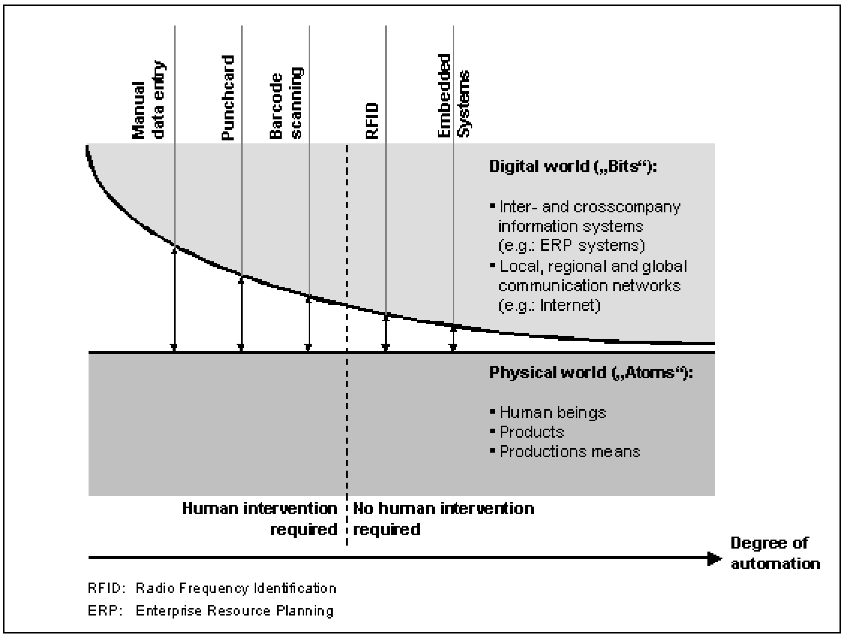

Fig. 1. Avoidance of Media Breaks [16]

Similarly, ubicomp technologies can have impacts on many other processes. For example, if there is real-time information about products in the supply chain available, production planning could be improved and fluctuations in the supply reduced. Ultimately, this could lead to a fully automated product driven supply chain. According to customer orders and supply under way, a smart warehouse could order the needed inventory from the suppliers or somewhere else where the needed parts are available.

Companies use quantitative metrics to measure business impacts. Return on Investment (ROI) and Total Cost of Ownership (TCO) are such metrics. To accomplish the measurements, it is necessary to describe benefits and cost in detail, which are influenced by the usage of ubicomp systems. Cost can be analysed in advance according to the utilized ubicomp system. Some of the benefits can only be estimated to a certain degree. For example, it is possible to calculate the volume of cost savings if all errors could be eliminated from production. However, it is not possible to exactly determine the increase of the sales as a result of the higher product quality.

Enterprises that plan to offer new products and services have the problem to predict the market behaviour. For example, in the telecommunication industry, Short Message Service (SMS) became very successful in Europe while the Wireless Application Protocol (WAP) based services did not [17]. It is difficult to predict how ubicomp-based appliances and services like smart sickbeds, smart umbrellas, new billing models based on usage time, or location based services will be accepted by the customers.

3.3 Application Cases

The previous paragraphs have shown which business problems can potentially be solved with ubicomp technologies and what the impact of ubicomp technologies could be. In the following, some practical experiences are taken into consideration. The M-Lab collected about eighty application cases from external sources to investigate where ubicomp technologies have the potential to improve existing processes and enable new services [18]. The analysis of application cases provides two benefits. Firstly, the technical feasibility of some solution can be shown. Secondly, the analysis allows to identify the concrete business impacts. In the following, three examples from the M-Lab collection are examined.

3.3.1 Example 1: Wireless Part Replenishment at Ford

Part replenishment is a time critical task in supply chain management. Material outages can stop the production process, which leads to less output. For efficiency reasons, inventory levels have to be kept as low as possible. To solve this problem, Ford has adopted a radio frequency based system for material replenishment. A communication infrastructure built of ceiling mounted antennas covers the whole production area. Wireless call buttons (RF transponders) are placed near assembly stations according to the preferences of the operator. Each call button is assigned to a particular part using a unique ID. By pressing the button, a request containing the ID is sent out and received by several antennas. The signals are forwarded to a location processor that aggregates the data and calculates the position from where the replenishment call came. The information is forwarded to a central server, which determines from the ID what part needs to be replenished.

Containers, which are stored near the production area, are also equipped with RF transponders. These devices are sending signals every 15 minutes. The signal is processed by the communication infrastructure. Once a replenishment call is received, the system can immediately tell an operator where the needed parts can be found. The data is also passed onto Ford's eSmart system. If the inventory falls below a predefined level, the system automatically sends out an order to the supplier. Ford has already implemented the solution in 25 plants. The system reduced material outages and inventory levels. The implementation cost has been lower than for a hard-wired solution [19]. Localization of products is the ubicomp technology that mainly provides the benefits of this solution.

3.3.2 Example 2: Fresh Food Tracking at Sainsbury

Perishable goods loose value through delays in the supply chain. The British retailer Sainsbury uses RFID technology to track chilled food products from receiving, through distribution, to the store shelf. Sainsbury receives food products from their suppliers in returnable transit packaging crates. The crates are tagged with smart labels. At the end of the chilled-food supplier's production lines, data including an expiry date is written to the labels. As the supplier dispatches the chilled food products, a portal reader records the tags. The information is forwarded to a central computer, which controls the distribution process. Inventory information can be updated automatically this way. The same happens again when the crates arrive at the distribution center. When a store orders chilled food, the system automatically tells the warehouse operators which crates to pick. Products being closer to their expiry date are chosen earlier. Check-out at the distribution center and check-in at the store trigger the update of inventory information [20].

The system allows full visibility of products in stock and their expiry dates. Sainsbury achieved additional shelf life time and better replenishment planning. Compared to the previous system that was based on barcodes, check-in and check-out activities are speeded from 2.5 hours to half an hour. Products can be located in the supply chain without searching. This saves time and is important in the case of recalls. In this case, automatic identification provides the main benefits.

3.3.3 Example 3: Cool Chain Management at Infineon

Infineon at Dresden buys temperature sensitive photo chemicals from a supplier in Amsterdam. During the transport, it can happen that the chemicals become exposed to hot temperature. If this happens for a certain time, they are perished and could cause damage during the later production process. To solve this problem, Infineon uses digital temperature loggers. They are put into the transport unit and perform continuous measurements. The temperature history can be requested from an infrared interface using a portable computer during transport and when the chemicals are received at Dresden. The data are processed into a XML format and transferred into the companies' SAP R/3 system using the SAP business connector interface [21].

The system makes sure to have reliable temperature data preventing damages during the later production process. Previously, traditional thermometers being able to log the maximum and minimum value have been used. Information about how long the goods were exposed to a certain temperature was missing. If damages are realised on the way, the goods can be returned immediately. In this example, sensor technology is the main ubicomp technology that provides benefits.

The three examples have pointed out the impact of the three ubicomp technologies automatic identification, localization, and sensor technology on business processes. In the following a ubicomp business process model is proposed relying on the presented concepts and examples.

3.4 Ubicomp Business Process Model

Process models are used to analyse and improve business activities. Well known is the value chain concept of Porter [22]. To support processes using IT, they must be specified in more detail. Most business software packages like ERP systems propose their own process reference models [23], [24]. As a first step in this direction, the ubicomp process model (Figure 2) identifies tasks and activities that can be supported by ubicomp technology. It shows a way to link the possibilities of the technology to business processes, thereby abstracting from the underlying technical infrastructure.

Functions are used to support tasks of a business process. In this paper, four basic functions are used. The components of the model are described next.

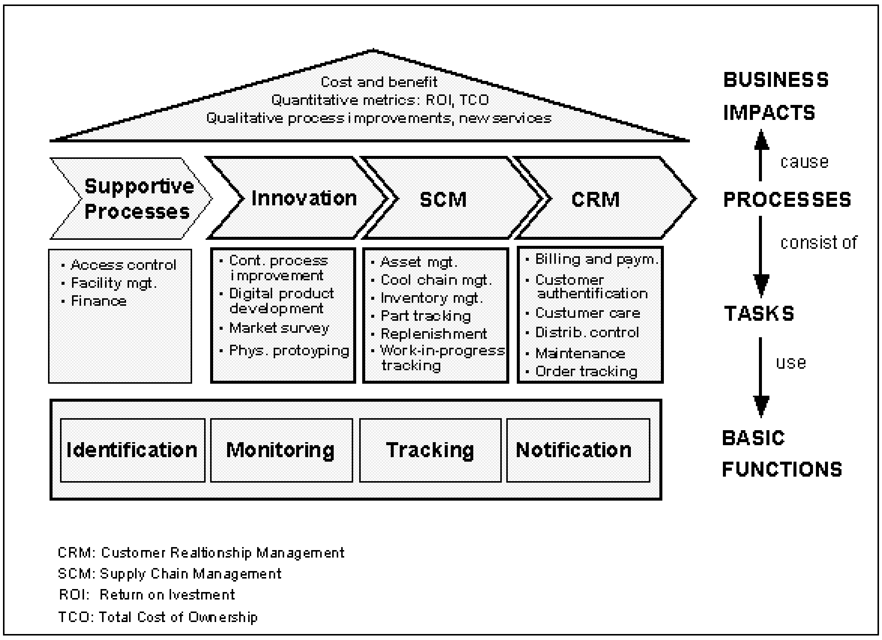

Fig. 2. Ubicomp Process Model

3.4.1 Basic Functions

The ubicomp process model uses four basic functions that turn physical objects into "smart objects". They provide unique identification, localization, and also physical status information dependent on their physical context, e.g. temperature, humidity, etc. Identification is used most frequently in applications combined with the other basic functions. The monitoring function refers to physical status information measured by sensors. Additionally, it provides a history of previous values. The tracking function refers to the object's location. It provides the current location and the previous locations of an object. Monitoring and tracking services can be provided by objects that are aware of their context, e.g. by the use of sensor technology.

The notification function enables smart objects to send out messages if a dedicated event has occurred. The corresponding rules can be interpreted as the business logic of the smart object and it appears that decisions are made from the objects themselves. Events are based on location data, status of an object, or messages received from other smart objects. If the temperature of a blood bottle exceeds a predefined value, a notification for the fridge, where it resides, could be triggered. If the problem persists, the notification might be forwarded to a technician. Smart appliances are able to take actions: the fridge lowers the temperature or it might perform self-checks.

This layer can also be regarded as the connection to the underlying technical considerations, which have been discussed in the previous section.

3.4.2 Processes and Tasks

Companies use IT systems in order to improve their processes. Normally, businesses comprise four macro processes: supply chain management (SCM), customer relationship management (CRM), the innovation process, and supportive processes. Each of these macro processes can be described by a number of tasks or more detailed activities. For example SCM: It encompasses all those activities associated with moving goods from the raw-material stage to the end user. This includes sourcing and procurement, production scheduling, order processing, inventory management, transportation, and warehousing. Existing standard business software increasingly tends to support all tasks of a process. There are still tasks or single activities that are not appropriately supported by existing IT systems. Ubicomp technologies can be applied to improve the execution of those tasks. The ubicomp process model identifies those tasks where ubicomp applications hold a high potential, e.g. tasks that are assigned to supply chain management comprise asset management, cool chain management, inventory management, part tracking, work-in-progress tracking, etc.

Table 1 presents the results of the application of the business process model on the three examples, which have been presented.

Table 1. Summary of Examples

	Ford Case	*Sainsbury Case*	*Infineon Case*
Business Impacts	Reduction of material outages, reduction of inventory levels, inventory visibility, cost savings over hard wired solutions in installation, and flexibility in adaptation to new production layouts	Additional shelf life time, more accurate replenishment planning, speeding up check-in and check-out processes, less perished goods, supply chain visibility	Prevention of damages during production, proof about who is responsible for perished chemicals, faster compensation of deliveries
Process	supply chain management	supply chain management	supply chain management
Tasks	inventory management, replenishment, container tracking	warehouse management, replenishment planning	cool chain management
Basic Functions	notification, tracking, identification	notification, tracking, identification	notification, monitoring

4 Conclusions and Future Prospects

Ubicomp technology enables a large number of new applications having impact on business processes. In section 3, it was shown that many scenarios that are technically feasible and beneficial can be found in areas like logistics, production, and retailing.

Those scenarios are mainly based on automatic identification, sensor technology, and localization. Section 2 has shortly surveyed the relevant technological aspects.

This paper focussed on applications that can be realized with today's technology and have positive business impacts, like the examples mentioned in section 3. However, it should also have become clear that the potential of ubicomp technologies will increase in the future. For example, a spare part can be tracked from the production, through the various distribution levels, to the end consumer. To achieve such a persistent collaboration throughout the supply chain, a ubiquitous infrastructure and middleware is necessary. This includes hardware aspects like the device, which is attached to the object, and the devices in the environment, which can communicate with their counterparts on the objects. Software aspects include protocols and languages for communication. The Internet domain provides open standards like TCP/IP and XML. Such a general ubicomp infrastructure, based on emerging technologies and standards, would enable some applications, which from today's perspective are more visionary.

For example, if all products would know their owner, theft would become almost impossible. If someone takes a product without permission of the owner, the product could automatically notify the owner or the police. As a result, businesses would save money. According to ECR (Efficient Consumer Response) European retailers loose about 1.75% of their sales because of shrinkage [25]. Additionally, there might be further impacts as a consequence of that one does not have to fear theft. For example, someone who lends out his bicycle would feel much more comfortable with ubicomp technology. Besides the prevention from theft, one may also request information on how extensive the bicycle was used. According to the usage, one could set a price and offer this kind of bicycle rental as new business service. This example shows how ubicomp enables new services and can have impact on everyday live, but it also shows that privacy issues cannot be disregarded. The person who has lent a bike may not wish to disclose where he or she has been.

A new concept in the ubicomp domain is the history of an item that can tell someone who it were, what was in its proximity, and what happened to it. This concept can be useful in different scenarios. A blind man, for example, can work efficiently in an office environment, since he or she has its own system to locate the required items. In such an open environment, it often can happen that jointly used items are placed somewhere, so that the blind man cannot find these items. Ubicomp with its new concepts may help in such a situation. If the missing item knows its position in the centimetre-scale, it can tell the blind man where it can be found.

Concluding, it can be stated that the usage of ubicomp technology can be beneficial at the present time in some applications already, and it can be expected that the progress in technology and the decrease of cost lead to more and new application scenarios. Analysing today's applications and the needs that drive companies to adopt ubicomp technologies, might give ideas how future applications could look like. The ubicomp business process model that has been sketched in this paper can be used as starting point to identify where ubicomp technologies have impact on businesses. Refining it and developing some more visionary scenarios is subject to further research.

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