Socially acceptable design of a ubiquitous system for monitoring elderly family members

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Abstract: Some functions in ambient assistance systems are enabled by sensors gathering data from the surroundings. While many prototypes are developed to prove technical concepts, for creating an acceptable, usable product additional facets need to be considered. Therefore, we present an approach to develop a functional ubiquitous system to support the monitoring and assistance of elderly family members. Besides the necessary technical concepts, insights from trust, law and user interface design are incorporated in this approach. The main idea of the approach is to deduce functional requirements from normative guidelines, theories or laws, and to combine the contributions from the involved disciplines developing the Senior Monitor demonstrator.

1 Introduction

While the average life expectancy in the European Union has been increasing since 1990, the number of newly born children has been decreasing since 1980. Altogether, these two phenomena have led to a changing situation in the European Union. Now, more Europeans are older and less are younger than 20 years ago. From research on the physical changes that come along with an increase in age, it is known that many physical abilities, like sensory, motor and cognitive abilities, decrease with an increase in age [Bi06]. When adults reach a higher age, limitations of the physical abilities can be so distinct that assistance and monitoring becomes necessary. When older adults need monitoring and assistance to stay healthy and active, their family members often have a key role in providing care for their older relatives. Cases, where the family members cannot do all the necessary assistance, are often supported by professional nursing service external to the family. In both cases, providing care has to exploit technical equipment to fulfill the older adults' needs. While certain kinds of assistance technology are already available, ubiquitous information and communication technology is just beginning to be used to provide ambient assistance to older adults and their care-giving relatives. Many needs of the older people can be supported by ubiquitous information and communication technology that provides ambient assistance. Besides comfort, well-being and social connection, health and the security of the older people are the most important ends for the ubiquitous computing systems that are used in ambient assisted living environments. Since it has become obvious that the development of new assistance systems needs not only technical proficiency but also the involvement of the system's future users, we have set out to develop a monitoring and assistance system for older adults focusing both on the technical and the socio-technical perspective on system design. This article shows that incorporating the socio-technical perspective into system design leads to a system that is more acceptable to its users than one developed from a purely technical perspective.

2 Related Work

The movement towards developing technical systems that support older people to stay more independent and secure is continuing on a wide-spread basis. Besides simple technical appliances that help older people and their care-givers to carry out daily activities, new information and communication systems are being developed that make taking care of older relatives more effective, efficient, comfortable and secure. Works that have been conducted in the area of ambient assistance technology are analytical, conceptual, prototypical, evaluating or combining any of these types of work. User-centered design methods like scenario-based design are used for the development of many prototypes [PMG11; RMG11; SSK11].

3 Requirements on the design of ubiquitous computing applications

UC applications support the user during his everyday life due to the use of sensory information to perform reasoning and adaptation [LY02]. The resulting requirements for the development process are described in the following. Apart from the opportunities which UC offers, it also entails considerable legal risks. Particularly, the data protection risks emerging from, e.g., ubiquitous elicitation, transmission and usage of personal data or from ubiquitous monitoring have to be considered [Ro07].

The law is an important aspect that needs to be considered unconditionally. Also, for actually being able to comply with all legal standards, it has to be considered as early as possible during the development process. Therefore, it is not sufficient to examine the system after the development process, such as it would be the case with conventional legal analysis. Rather, legal experts already need to be integrated into the demand analysis, so that legal requirements can be integrated through individual steps into the designed technology.

The design of new technologies, especially those from the Ubiquitous Computing background, issues a challenge for the law in general. On the one hand, the law requirements have to be fulfilled, while on the other hand the technical development requires adjusted concepts that consider these new developments that are currently not covered by law.

However, in principle, the law does not contain concrete requirements for the design of technical systems. This is especially true for constitutional law, which is more abstract than general legislation. Nevertheless, these laws have to be implemented by system designers, which is why legal experts are needed right from the start during all stages of the development process.

A challenge in UC is the creation of an unobtrusive user-friendly interface. Such an interface should not require specific skills or training [Sp08]. Additionally, an adaptive interface which can still be controlled by the user is required. If the system should autonomously adapt to an unexpected state, resulting in an unexpected behavior, the user might be negatively affected. Therefore, usability is a crucial issue in the development process, and expertise needs to be incorporated.

The on-going development of UC technologies will make applications more and more complex, thus enhancing the importance of trust is an important mechanism for perceived complexity reduction to the user [Lu79]. Research on technology acceptance suggests that trust is a key determinant of technology adoption and usage [LS04]. Concerning unknown technologies and applications, the initial trust of the user is crucial because the user has not yet had their own experiences. Creating this initial trust during the development of UC applications is an additional challenge in UC development.

4 Development proposal for UC

This section provides an overview of the phases and activities of our initial development proposal [HSF11] and the methods being applied. The core of the development proposal is an iterative development approach that consists of analysis, conceptual and software design, as well as implementation and evaluation (Figure 1).

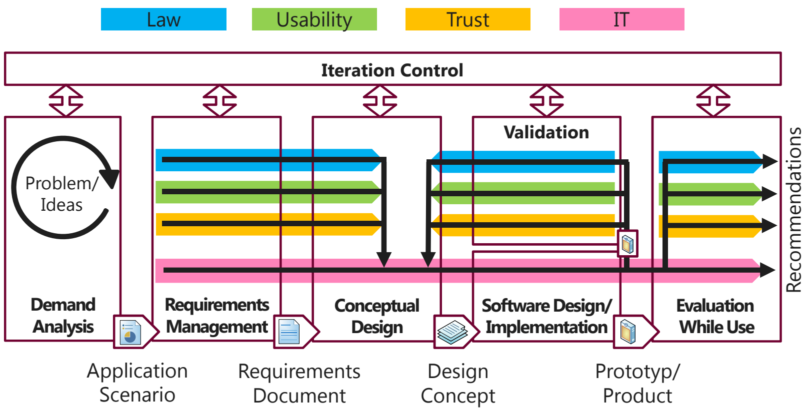

Figure 1. Development proposal for UC applications (following [HSF11])

First activities in the development process include defining appropriate goals and writing application scenarios in the demand analysis in order to establish a multidisciplinary understanding of the purpose of the UC application. Furthermore, the scenario includes a business model for the planned UC application. The extended scenarios are used afterwards to elicit requirements. Our approach considers conventional requirements that are generally used in system development. It incorporates furthermore methods for acquiring expert requirements. In order to acquire functional requirements from law, the first three tiers of the KORA method [HPR93] have been used. This procedure is analogously accomplished for usability [BJR12] and trust [SHH12]. After the requirement analysis, the requirements need to be joined. Therefore, the procedure of the EasyWinWin-method is adapted to our special needs. The result is a shared requirements document with negotiated requirements.

The requirements document is the basis for developing a consistent concept design. In this stage the artifacts: use cases, application workflow, screen design and back-end architecture are elaborated upon. There are persons in charge for every step which consult the experts in case if the person in charge is not able to treat single requirements. Experts continuously review the resulting artifacts. If necessary, new solutions get elaborated in multidisciplinary collaboration.

The implementation of the application is planned and conducted during the stages of software design and implementation. During the iterative implementation, prototypes are built and then regularly tested against the negotiated requirements. The results are used to modify the application design. The application is evaluated using a combination of methods established within the involved disciplines, adapted to the use case.

5 The Senior Monitor demonstrator

The case study that is used in this paper to form the basis for the examination of a socially acceptable design of a ubiquitous system is the monitoring of elderly people in order to enable them to live an autonomous life even at an old age. To provide this possibility, we illustrate the Senior Monitor demonstrator. This demonstrator provides the opportunity to monitor elderly family members in their familiar surroundings.

The possibility to monitor elderly family members, e. g. the own mother, has become more and more important in the last couple of years. This is due to the fact that on the one hand younger people have to be more flexible with regard to their working places and their places of residence, which leads to the fact that they often live far apart from their parents. On the other hand, pervasive sensor technologies included in current mobile phones [LD10] or in current smart home automation systems penetrate our lives and provide an easy possibility to get up-to-date information of people, even if they do live far apart.

This need of people to get information about their family members who live far apart using mobile sensor technology is called SoLin (Social Link) [DLK11].

For this reason, the Senior Monitor provides interested family members or those who are in charge to take care of them the opportunity to open an information window from their current position straight into the apartment of their relatives. With the help of this information window, family members can get an overview whether their elderly family members are doing well or if they need something, e.g. medical support. Further, the elderly family member can be sure that their family will notice emergencies that might occur to her.

To initiate this information window, the senior apartment demonstrator mainly consists of two components. The first component is the elder person’s flat, which automatically offers sensor-based context information about the elderly person and the second component is a program that visualizes this information in real time. In our first version of this demonstrator, the information is visualized using a web interface, as depicted in Figure 2. The picture shows the outlines of the senior flat; the places of the different sensors installed in this flat, and give an overview of different aggregated context information of the senior person.

Altogether, a family member, e.g. the son, can access the following context information using the web interface: doors or windows open or closed, the current temperature, humidity and light intensity in her rooms; whether her dishwasher, the microwave or the TV has been turned on; in which room the elderly person is currently present.

Based on this simple context information, it can be further derived whether the senior has a visitor, if the room status is OK even if her current status is OK or not. The current room status depends on the facts whether the temperature and humidity is normal and whether her electrical devices work properly. Her current status depends whether she has been active enough during the day or not.

Based on the overall goal that an elderly family member should be supported to live autonomously using the Senior Monitor, the following requirements have to be considered from the view of computer science:

- ubiquitous sensor technology has to be installed
- the sensors have to be unobtrusive
- contexts provided by inconspicuous sensors should give information on the status of the elderly person and on the status of her flat
- context information has to be automatically processed, interpreted and saved on a context server architecture
- saved and interpreted context information are displayed directly on the Senior Monitor demonstrator

To fulfill these requirements we used sensor technology that can be installed in the flat in an unobtrusive way. Therefore, we used sensors from Phidget Inc. [Ph12] and ELV electronic [El12] and sensors that are available in common smart phones. Phidgets and ELV sensors are basically used to derive context information on the flat. These contexts describe whether the doors and the windows of the flat are opened or closed or if they are opened for a long time. Further, these sensors are, e.g., used to detect the elderly person is cooking and to detect whether she is currently located in her flat. If the cooker is turned on for a long time and the person is not located in the kitchen, there might be a potential risk for her and others' safety.

To derive the personal status of an elderly person, we used Phidgets sensors and sensor technology from a smart phone (Samsung Galaxy S2) equally. Infrared Phidgets sensors are used to detect whether the person is moving sufficiently and the acceleration sensor from a smart phone that the person is carrying in her trouser pocket is used to detect her current movement action, similar to the approach presented in [LD10].

Furthermore, green spots on the web interface represent the real positions of the sensors in the flat display simple context information provided by the installed sensors. The information of these sensors can be accessed by utilizing the mouse over event. Aggregated information such as the room and the senior status are displayed as textual information on the web interface.

The Senior Monitor V. 1.0 was extended and re-designed using the development methodology outlined in the next sections. The version 2.0 of the Senior Monitor will be presented during the discussion of the concept design phase. Version 2.0 of the senior apartment demonstrator is ported to the iPad to offer a more intuitive handling. Further, the second version will include new features like representing the senior's current blood pressure and pulse value, indicating contexts that show whether she is cooking and which hotplates are active or not. Additionally the second version of the demonstrator has been completely redesigned with the methods described in this paper regarding aspects of law, aspects of trust and aspects of user interface design.

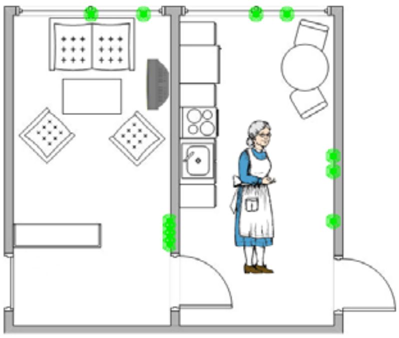

Figure 2: Screenshots of Version 1.0 of the Senior Monitor

6 Demand analysis

As described in our development proposal, the first phase of the development process is the demand analysis. Since the idea of the Senior Monitor has been well established with the first version, we do not need a new application goal. Nevertheless, a brief description of the main goal remote care for elder people builds the basis for further development activities. From this rather abstract starting point, two different scenarios have been elaborated upon.

The scenarios are described from the perspective of a user, showing a typical set of user interactions with the planned system. The scenarios serve as a base for identifying tasks the user might accomplish. The described interactions in the scenarios support the requirements analysis and interface design. The level of abstraction illustrates how the user interacts with the application, but it does not contain any technical details to serve as foundation for the requirements analysis. It does not restrict the possibilities of technology design. Furthermore, this abstraction level allows all stakeholders to understand the requirements. This is essential for the later consideration of requirements from law, usability and trust.

We used these artifacts for a first validation of the planned system. Scenarios were presented to potential users of the system. They were asked to raise concerns and to give ideas for improvement. With this feedback, we could adjust the scenarios to real user needs and expectations. The scenarios and the business model thus ensure a shared understanding of the purpose and goals of the application and are the basis for acquiring requirements from law, usability, trust, and other stakeholders for further application development.

7 Requirements management

After the demand analysis, we elaborated upon the requirements for the further development process. Accordingly, we elicited conventional requirements as well as expert requirements in order to realize legal provisions and promote usability and trust.

The requirements of the stakeholder (the son) for the second version of the Senior Monitor are the following: A haptic control concept of the Senior Monitor that is more intuitive than the web interface used in the first version. Most interesting information like the status of the elderly person and the status of the room is presented concisely. The flat of the senior has to be pictured more intuitively. The status of electrical devices, single context information like the temperature and aggregated context information like the status of the oven has to be presented more illustratively.

Using the method for trust engineering [SHH12], we were able to formulate trust-related functional requirements. Based on trust theory [Lu79], three dimensions form the user's trust in Senior Monitor: performance, process, and purpose. The performance dimension reflects the capability of the system in helping the user to achieve his goals, the process dimension reflects the user's perception regarding the degree to which the system's algorithms are appropriate, and the purpose dimension reflects the user's perception of the intentions that the designers of the system have. These dimensions itself are formed by several antecedents, such as Information accuracy – focusing on the aspect that the information provided by the system is accurate - for the performance dimension. Following insights on requirements engineering, such antecedents can be interpreted as under-specified functional requirements [Po08]. Thus, they are translated into functional requirements. An exemplary trust-related functional requirement derived based on the antecedent information accuracy is: *the user shall be able to access information on how recent the provided contexts are*.

The analysis of usability requirements was based on the human-centered design process of interactive systems (ISO 9241-210) [Ge11]. In order to analyze the context of use, interviews with potential users who take care of an elder family member were carried out. The focus of the interviews was on typical activities intended to support elderly family members, about typical situations in which supporting activities take place, about the challenges these activities impose on the supporting family members and on possible measures to resolve the challenges for the care-taking family members and improve the quality of support. Since the answers of the representative users that were taken up during the interviews ranged from basic underspecified requirements to concrete requirements for technical assistance in a specific situation, they were grouped based on their degree of specificity and whether they included a functional requirement or a non-functional requirement. Main requirements derived from the use context analysis included:

- The relatives are supposed to have access to all the information that is relevant for taking care of the older family members.

- The system is supposed to detect the older family member's personal well-being.

- The display of the sensory information is supposed to be self-explanatory to the user from the first usage on.

- The aggregation of sensory data into context information is supposed to lead to uniquely identifiable situations.

For the following phase of the system development, in which the design concept is created from a selection from the list of functional and non-functional requirements, all the usability requirements were tried to be broken down into concrete, detailed functional requirements to allow the concept designer to make reasoned decisions on all design details based on the usability requirements.

For the legal requirements, we had to use a different approach during the requirements management process. Here, the difficulty exists that legal statutes around the world rarely contain functional requirements. This is especially true for constitutional rights, because they are often phrased quite abstract. That is simply because constitutional rights regulate human coexistence instead of how to use technical systems. Nevertheless, the system designer has to implement legal requirements into his technology to comply with the law in general and constitutional rights in particular. This does not mean that technical developments shall be compromised through law; in contrast, this method aims to have a positive influence on the design process and implements greater legal goals and requirements into technical design proposals in a systematic and comprehensible way. Thus, the technical system will safeguard these requirements directly and accordingly regulate the use of this application in accordance with the law. To overcome the gap between the legal requirements and designing the final product, we used the before mentioned KORA method. KORA is more than a usual legal assessment. It goes one step further, because it results in concrete instructions and detailed requirements directly pointed at one technology. KORA translates superordinate legal goals and requirements into technical development proposals. Hereby, the legal provision, such as constitutional rights, will be directly guaranteed by means of the Senior Monitor application. The KORA approach assures traceability to the higher order provisions. Additionally, the linguistic change from the respective terminologies to a more generally understandable language is provided.

For acquiring requirements from law, we identified as a first step legal provisions from constitutional rights. Taking the German constitutional right to personal freedom (Article 2 para1 Basic Law of the Federal Republic of Germany) as an example, we identified that the right to informational self-determination – the freedom of every single user to decide whether he wants his personal data to be used or exposed – has to be protected. These provisions were concretized to legal criteria which contain relations to technical functions as well as to the legal and social aspects. One of the criteria derived from informational self-determination was transparency. It signifies that the data collection and data use needs to be transparent for the respective user as well as for the data subject (in this case the senior). The last step of KORA that is considered part of the requirements management process is the derivation of functional requirements from these criteria. A coherent functional requirement in this case was the traceability of the procedures and their data within this application by the user and the data subject.

Some crucial legal requirement we also considered important for the Senior Monitor application were:

- The user as well as the monitored person shall understand which data (about him/her) is and will be collected as well as the purpose for which this data will be used.
- The user as well as the monitored person shall comprehend which data has been stored about him/her in the past.
- The monitored person shall have the possibility to interrupt the sensors and the data stream.

- Before submitting any data to a third person (for example to a doctor) the monitored person shall give consent to the submission. This consent shall be revocable.

All of these requirements influence the constitutional rights of informational self-determination, the protection from physical and psychical damages to the health, the potential for development and self-realization (for the monitored and the user) as well as equal opportunities for both of them.

About half of all Senior-Monitor requirements were expert requirements, pointing out the impact of the involved experts. Some of these requirements were congruent, because different disciplines came up with requirements that meant the same. Because of possibly congruent and conflictive requirements, negotiation was required.

For the negotiation, we adapted the EasyWinWin-method. The method has been conducted in a workshop by all stakeholders, including one expert from the involved disciplines. The first step of the workshop served to enforce a mutual understanding of all requirements between all stakeholders. Ambiguous requirements were explained and, if necessary, restated. In this way, we identified terms which could have different definitions in the involved disciplines. These terms were redefined to a consistent vocabulary, and then summarized in a glossary together with application specific terms and definitions. Further, we could identify some requirements from various disciplines that were formulated differently but meant the same. From such requirements we formulated one common requirement. In the next step, the stakeholders could rate the requirements along importance and ease of realization, where high variances of the ratings indicated misunderstandings between the participants [Gr00]. After this step, the participants could write issues and further options to single requirements. In a discussion, the stakeholders checked these issues and options and restated the requirements if necessary.

Some requirements were mandatory, which, if not realized, could have an unlawful application as a consequence. These requirements needed to be added to the requirements document. The other requirements were prioritized and those with low priority were cancelled. Additionally, new requirements were identified, discussed and added to the requirements document.

The unsorted requirements were, if possible, grouped to function blocks. This facilitated the further development of the application. Requirements belonging to multiple function blocks were collected in a comprehensive block. Finally, the sorted requirements and the glossary were combined to a requirements document.

8 Concept design

We developed the work flow and the screen design iteratively. The initial version of the screen design has been developed by a human-computer interaction expert, based on all relevant functional and non-functional requirements from the requirements document.

The main outcome of the concept design phase is a document in which specifications on the screen layout and design, icons, information flow and interaction between man and machine are combined in a clear way. This document serves as a basis for programming the application. After the initial version of the concept design had been created, enhancements were added and change requests were inserted from trust and law.

Figure 3: Screenshots of the design mock up of version 2.0 of the application.

9 System development

To collect context information that is visualized in the Senior Monitor v2.0 demonstrator, we utilized different sensor technologies like phidgets [Ph12] and ELV sensors [El11]. In this process, the ELV sensors have been used to capture the motion of the senior, to collect information with regard to the current status of the windows and doors and to detect her habits using different electrical devices. The phidget sensors have been used to collect data with regard to humidity, temperature and light intensity. All sensors were implemented in such a way that they are unobtrusive and do not disturb an elderly person during her daily activities.

All gathered context information is automatically sent to a context server architecture. This context server has three tasks. First, storing all gathered context information. Secondly, to inform services which have been registered to certain context information to automatically pre-process accumulated sensory data. Third, to make already stored and pre-processed context information available to the Senior Monitor demonstrator. The communication flow between the sensors, the context server and the iPad to visualize the context information to the son is shown in Figure 4.

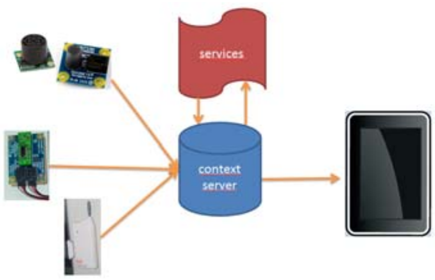

Figure 4: Communication flow of the context data used by the Senior Monitor 2.0

10 System Evaluation and User Evaluation

Every technical system needs evaluations at every development stage in order to test the system’s functions against functional and non-functional requirements. In the underlying case, the Senior Monitor software was tested by the software developer after completing the implementation of any new version. This method, which is part of the extreme programming (XP) software development paradigm, allows testing of the functionalities already implemented in the current version of the application. A successful test of all functionalities confirms the software’s compliance with the requirements list. After the application for the user interface was finished, the correct integration of all the technical components of the system, i.e. the sensors, the context server and the user interface, is carried out in order to confirm that all the technical subsystems work together in the way intended by the developers in the system idea. After the correct implementation and integration of all necessary system functionalities has been confirmed in a series of component tests and integration tests, usability tests have been carried out with future users of the system.

While usability evaluations can be carried out at any stage of system development with mock ups and a suitable method for making the user experience the mock up, our user evaluation of the Senior Monitor uses a fully integrated prototype of the system, and provides the users with the chance to freely explore the system’s functionalities. In addition, two central use cases of the system are presented to the users:

1. Seeking information about the grandmother’s health and the state of her apartment and

2. An alarm.

Both situations are induced by the evaluator. After the exploration and test of the integrated system prototype, the participants will be interviewed, using questions about the usability, trustworthiness and legitimacy of the application, based on an interview guideline. The guideline includes questions from every discipline that contributed functional and non-functional requirements during the requirements management phase. Some of the central questions for our evaluation included:

- Did the application help you to inform yourself on the situation in the apartment?

- Would the application help you to get informed about the well-being of your relatives?

- Would the application help you to help your older relatives in certain situations?

- Were you able to trace which data were processed about your relatives?

- Did you have the feeling that the collected data were necessary to ascertain the effectiveness and efficiency of the application?

- What, for you, is trust, and how do you trust the application?

The interviews are conducted with participants from the group of care-giving relatives of senior family members, and the answers to the questions in the interview are evaluated qualitatively. This means that every answer is assigned to a category and all the answers that contain equivalent statements and content are grouped, so that both a qualitative description of the users' perceptions of usability, trust and law and a relation to system properties and a quantitative measure of how common the perceptions were among the participants are given.

In our evaluation, we compare the acceptability of version 1.0 of the system, that was developed from an information technology perspective, and version 2.0, which was developed from a trans-disciplinary technical and socio-technical perspective to find out how usable, trust-worthy and legitimate both versions of the system are, and to find out whether the multidisciplinary development method leads to higher acceptability with respect to usability, trust and legitimacy than the version developed out of a purely information technological perspective.

11 Discussion and Conclusion

During the development of the Senior Monitor demonstrator, some activities were successful and others were more difficult. Optimally, it is important to assign every task in the development process to a competent and experienced member of the staff who is responsible for the quality and punctuality of the results he or she is agreed to deliver. Second, it is important to provide the necessary resources to fill all the roles that are needed for a successful development. In our case, work flow management was not filled by a dedicated expert, which led to the problem of coordinating the cooperative process of the individual staff members. One important procedure during the development of the system is breaking down abstract use requirements to functional requirements. While methods like KORA, that help breaking down abstract requirements into functional requirements, rely on the experience and skill level of the staff members, some abstract requirements were difficult to be broken down into specific functional and non-functional requirements. During the development of the system, the experts found out in an expert evaluation that Version 2.0 of the system is more socially acceptable than Version 1.0.

Furthermore, it is crucial for every expert area during the requirements management process to prioritize the formulated requirements, in order to work effectively and efficiently during development. It may happen that some of the requirements contradict with technical possibilities. In this case, it is quite essential to know which requirement has to be seen as a "must-have" and which one is more of a "nice-to-have". However, for example in the area of law, most of the identified requirements are predetermined through law and thus have to be considered, but even there are still some additional requirements that can be seen as optional. This procedure guarantees that important requirements are actually met and administered primarily.

Overall, the application of the method has led to an improved senior monitor prototype. This has been proved by the positive feedback from the participants of the evaluation. The cooperation of the involved disciplines could be optimized, but it also became apparent that coordination of tasks could be further improved. In a next step, all the aspects of the already developed system that successfully enabled usability, trust and law, will be extracted into design patterns for socially acceptable systems.

Our contribution shows that the trans-disciplinary development of ubiquitous computer systems from technical and socio-technical perspectives is likely to improve acceptability of new information systems by their future users. Whether or not the increased effort and cost that are needed to conduct this type of development work can be brought up in practice and how the necessary resources needed to realize development projects of this kind can be brought up will be subject to further research.

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