# User-driven design of a context-aware application: an ambient-intelligent nurse call system

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***Abstract*—The envisioned ambient-intelligent patient room contains numerous devices to sense and adjust the environment, monitor patients and support caregivers. Context-aware techniques are often used to combine and exploit the heterogeneous data offered by these devices to improve the provision of continuous care. However, the adoption of context-aware applications is lagging behind what could be expected, because they are not adapted to the daily work practices of the users, a lack of personalization of the services and not tackling problems such as the need of the users for control. To mediate this, an interdisciplinary methodology was investigated and designed in this research to involve the users in each step of the development cycle of the context-aware application. The methodology was used to develop an ambient-intelligent nurse call system, which uses gathered context data to find the most appropriate caregivers to handle a call of a patient and generate new calls based on sensor data. Moreover, a smartphone application was developed for the caregivers to receive and assess calls. The lessons learned during the user-driven development of this system are highlighted.**

## I. Introduction

The envisioned ambient-intelligent care room [1] comprises plenty of sensors to sense the needs and preferences of the staff and patients and devices that work together to adapt the environment to support them in carrying out their daily activities. To realize this vision, context-aware techniques are often used to combine and exploit the heterogeneous data offered by all this technology to improve the provision of continuous care [2]. E.g., if the system is able to determine the caregiver's task and the patient's condition, it can automatically adapt the environment to their needs, e.g., adjust the light level or show relevant information about the task.

However, the adoption of context-aware services is lagging behind what could be expected. Whereas the healthcare industry is quick to exploit the latest medical technology, they are reluctant adopters of modern health information systems [3]. Half of all computer-based information systems fail due to user resistance and staff interference [4]. The main complaint made against mobile, context-aware systems is that users had to significantly alter workflow patterns to accommodate the system [5]. This is due to inadequate techniques for personalization of the services, a lack of focus on the soft aspects of interaction, e.g., automated and personalized alerts, and the lack of tackling problems such as the need of the users for control [6]. To ensure that technology and environment blend into each other, the users should be involved in each step of the development cycle of the applications [7].

Therefore, an interdisciplinary methodology was designed to develop a prototype context-aware application. Social scientists, engineers and users, e.g., doctors, caregivers and healthcare industry professionals, were involved in every step of the development process. The research started from the needs and daily work practices of the stakeholder to determine the ideal prototype application to develop. It was found that a nurse call system is an important way to coordinate work, communicate and provide continuous care.

Traditional nurse call systems are static as calls are made by buttons fixed to a wall and the nurse call algorithm consists of predefined links between rooms and caregivers' beepers [8]. They do not take into account the current situation to assist the user in making calls, assign a nurse to a call or detect hazardous situations for which a call should be made. Moreover, the beepers give the caregivers limited context information about the call.

In this research, the user-driven approach was used to develop a dynamic, ambient-intelligent nurse call system. It integrates the heterogeneous data collected by the devices, e.g., location data, medical parameters and domotics data. The system uses this information to find the most appropriate caregiver to handle the call of a patient and even to generate calls based on the context information, e.g., when a patient spikes a fever. Moreover, a smartphone application was developed, which is used by the caregivers to receive calls, assess & redirect them, contact the patient, etc. The users were involved in each step of the development process of this ambient-intelligent system to determine the prevalent context information that should be taken into account, the algorithms which should be used to generate, assign and prioritize nurse calls and the requirements and user interface of the mobile application.

The remainder of this paper is structured as follows. Section II details the ambient-intelligent nurse call system and developed mobile application. Section III discusses the user-driven methodology which was used to develop this system.

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The lessons learned from designing the context-aware application with this methodology are discussed in Section IV. Finally, Section V highlights the conclusions and future work.

## II. The ambient-intelligent nurse call system

### A. General architecture

The architecture of the ambient-intelligent nurse call system, which was developed using the user-driven methodology described in Section III, is shown in Figure 1. Each patient and caregiver has a badge to locate this person. Each badge also has a call button allowing patients and staff to walk around freely and still make (assistance) calls. The ambient-intelligent care environment contains numerous devices & sensors that sense the context and collect information about the environment. A desktop provides the head nurse with a user-friendly interface to input and visualize information about the department, e.g., the number of patients and available caregivers and their characteristics and roles. Each staff member is notified of calls assigned to him/her by a smartphone application, which is discussed further in Section II-B.

The *Context-aware Platform* [9], [10], depicted at the top of Figure 1, handles the communication to and from all the devices and sensors. The *Context Interpreter* uses an ontology [11] to interpret the provided heterogeneous data. An ontology formally describes the concepts in a domain, their relationships and attributes. The used ontology models all the necessary context information about the continuous care domain, e.g., the profiles of the staff & patients, the possible tasks & calls and knowledge about the devices and sensors. This ontology was developed using a participatory ontology engineering methodology, as discussed in Bleumers, et al. [12].

When new data is inserted in the ontology, the *Context Interpreter* uses reasoners [13] and rules to infer new knowledge out of this information. For example, when a new call is inserted, the *Context Interpreter* assigns the most appropriate staff member to this call based on the available context data using the algorithm that is discussed in Section II-B.

The *Context Providers* are responsible for translating the information, delivered by the various devices and the database, to data that can be inserted in the ontology. The *Query Services* do the exact opposite, they transform the data and conclusions inferred by the *Context Interpreter* to information that can be processed by the various devices. This can result in changed status of a device, e.g., dimming a light, or in a message that alerts a staff member, e.g, about an assigned nurse call.

### B. Mobile nurse call application and nurse call algorithm

The ambient-intelligent nurse call system differentiates between 3 types of calls. Normal calls are initiated by patients pushing a button. Caregivers can launch assistance calls to ask for help by pushing a call button or the orange hexagon on the mobile application, as shown at the upper right of Figure 2(a). Finally, context calls are generated by the nurse call system as a consequence of measured sensor values, e.g., a temperature sensor indicates that a patient is spiking a fever.

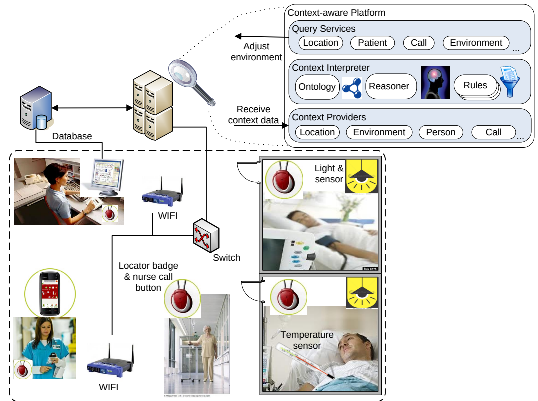
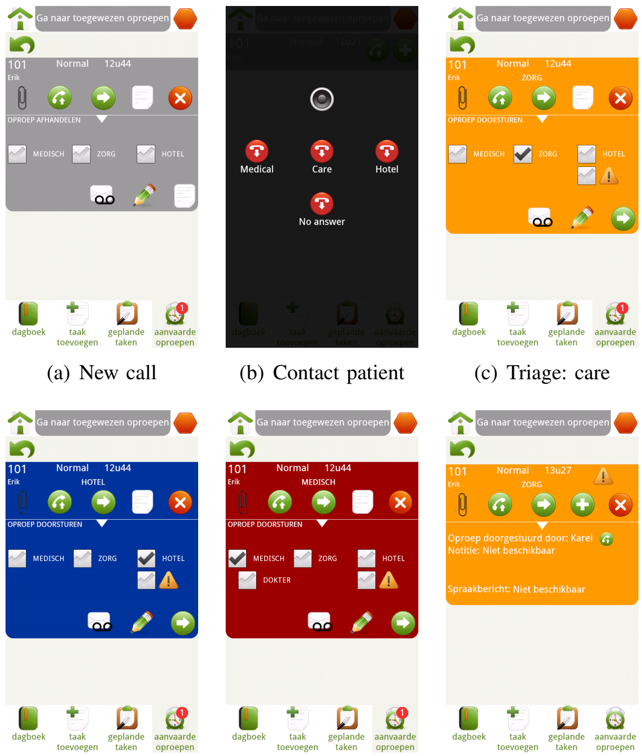



Fig. 1. General architecture of the ambient-intelligent nurse call system.

When the ambient-intelligent system receives or generates a call, the rule-based algorithm finds the most appropriate caregivers to handle it. It first determines the patient for whom the call is made. Next, the algorithm finds all the staff members who have a high degree of trust relationship with this patient, e.g., a therapeutic or personal relationship. If no such staff members are found, this step is ignored. Out of these filtered staff members, caregivers are preferred who are close to the patient and not busy with a high priority task. This algorithm allows rapidly finding caregivers to initially assess the call.

When the staff receive the assigned call on their smartphones, it vibrates to avoid noise overload. As shown in Figure 2(a), the associated patient, the number of times he/she has pushed the button and the location, type and timestamp of the call are visualized. For a context call, the sensor and values that caused the call to be generated are also shown. The caregiver can decide to go to the patient and handle the call, but he/she can also contact the patient to assess the reason and importance of the call by clicking the green telephone icon. A telephone call is made to the handheld device of the patient to preserve privacy. However, if the patient does not pick up after three rings, the call is established through the intercom in the room terminal. After contacting the patient, the caregiver can triage the call, as shown in Figure 2(b), by indicating whether the reason is a caring task, medical task or hotel funtion, e.g., a glass of water. As depicted in Figures 2(c), 2(e) and 2(d), the color of the call changes to reflect its reason. After this assessment, the caregiver can indicate on the smarthpone that he/she is going to handle the call. The call then disappears from the smartphones from the other assigned caregivers. As visualized in Figure 2(a), the person who accepted the call can still see it by clicking the button "accepted calls" in the lower right corner. It indicates the number of accepted calls in a red circle. The caregiver can also decide to add information to the call, e.g., by jotting down a note (pencil button) or changing the reason. Finally, the caregiver can also finish the call remotely by clicking the white paper button. The context of the call and the information provided by the caregiver are automatically transferred to the care registration file of the patient, which can be checked by clicking the lower left button.

However, the caregiver can also decide to redirect the call, e.g., because he/she does not have the required competencies,




(a) New call (b) Contact patient (c) Triage: care

(d) Triage: hotel (e) Triage: medical (f) Redirected call

Fig. 2. Screenshots of the user interface of the mobile nurse call application

by pressing the green right arrow, shown in Figure 2(a). Figures 2(c), 2(e) and 2(d) show the redirection screen of a call with a care, hotel function and medical reason respectively. For the latter category it can also be specified that a doctor is needed. The caregiver can change the reason, indicate that the call is urgent or add a note. When the call is redirected, the nurse call system uses a more complex algorithm to find staff members to handle the call, which takes into account the context information provided by the first caregiver. As the reason of the call is known the algorithm first filters the staff members with the appropriate competencies to handle the call. The algorithm prefers staff members who have this competence as part of their current role, but it also considers caregivers who have these competencies through secondary roles, separately acquired competencies or experience. If no staff member is found with the required competencies, this step is skipped and the previously detailed nurse call algorithm is used. As it is most important for urgent calls that a caregiver is quickly able to handle the patient, the algorithm does not take the trust relationship into account for these calls. More weight is thus given to the distance and current task parameters.

The newly assigned staff members receive the redirected call on their smartphone as shown in Figure 2(f). If the call has priority urgent, the smartphone rings instead of vibrating. The caregiver can contact the person who redirected the call and access all the information that was previously provided. This staff member can also decide to immediately handle the call, to redirect, accept or finish the call or to contact the patient.

To illustrate the integration of the nurse call system with the devices in the environment, it does not only generate calls based on gathered sensor data, but also adjusts the light level in the room based on the reason of the call and the presence of caregivers and unlocks the supply closet when a person with the appropriate competencies logs in on the room terminal.

The next Section describes how the user-driven desing process helped to shape the described context-aware application.

## III. User-driven design

### A. *Observations: define goals and scope of the prototype*

The user-driven design started with a user and task analysis. By observing and interviewing the target users in their environment, their needs and wishes about their daily tasks were determined. Two types of care settings were observed: a hospital and a residential care setting for people with a cognitive and/or physical impairment. The observations focussed on the communication between caregivers and with their patients.

It was observed how stakeholders use their nurse call systems. Within the team, there are routines about who handles which patients and people communicate when they are temporarily unavailable. The caregiver needs to go to the room of the caller to determine the urgency and reason of the call and whether they need additional care prodcuts to handle it. This leads to a lot of extra miles for the caregivers and a need to interrupt their current tasks to assess the call. In care settings there are many sound signals, e.g., beepers, phones ringing and monitoring equipment. Participants noted they cope with a sound signal overload and became immune to it. Caregivers working the night shifts mentioned that sleeping patients woke up bacause of their beepers. Moreover, staff members do not always take their beeper with them as they find the beeping annoying when they are helping someone and cannot leave anyway. From a patient view, a lack of feedback after making a call was observed. Patients were left with questions, e.g., “Did they hear me?” and “How long will I need to wait?”. Finally, a high demand of care registration at the point and time of care was observed. This is now done after the shift.

In the hospital setting, the nurse call system had a room to room intercom feature. This allowed a nurse to contact patients before coming to their room. Even though this feature could provide additional information and give feedback to the patient, it was not used. This was due to privacy reasons as other patients in the room could follow the conversation. Also, patients mentioned that it was awkward to hear a voice in the room, without being able to determine where it came from.

Depending on these users’ needs and abilities, the following requirements were derived for the ambient-intelligent nurse call system. The nurse call algorithm should take into account context, e.g., the walking distance and the availability, role & competences of the caregiver. To allow mobile care registration and requests, each patient should have a mobile nurse call button and each staff member should have a smartphone with a care application. Moreover, detailed information about the call should be visualized on the smartphone, e.g., who and where is the patient and the reason, urgency and timestamp of the call. This demands a way to localize the patients and caregivers at all times. The application should assist the caregiver with registering information about the call on the fly. The smartphone should allow the caregiver to contact the patient from anywhere in the environment to provide feedback to the patient. To preserve privacy and confuse the patient less, contact should be established through a personal device of the patient, e.g., a handheld device or the wheelchair. However, if the patient cannot be reached, the intercom should be tried. To decrease the noise overload, the smartphone should vibrate instead of ring when a call is received that is not urgent. Finally, when the system is installed, continuous training should be given about all the features to increase acceptance.

### *B. White book & sunny-day scenario*

In order to keep an overview of the requirements and objectives of the novel ambient-intelligent nurse call system, a *white book* was created as central coordination instrument between the software engineers, user researchers and stakeholders. The construction of the white book was started after the first observations, but the document continued to grow and adapt during the whole development cycle of the system.

The white book starts with the description of various personas. Personas highlight the representative user archetypes of a system, the activities they wish to perform, why they wish to use the system and how the system fits into the context of their life. Their main advantage is that they allow feeling empathy for the user group, as they put a human face to a list of requirements. As such, they explain the origins of the requirements and why certain design decision are made. In total 13 personas were created. The persona Erik lives at a care residence, has Duchenne disease and is dependent on a wheelchair. Personas were also created for Erik's parents and brother, staff at the care residence and associated hospital.

Second, a sunny-day scenario is described. A scenario is a story that describes the hypothetical use of a system to help develop a detailed and shared understanding of the context and activities of the users. The scenario consists of a number of scenes in which the actions of the personas are described such that the functionalities of the novel system become clear. The scenario is sunny-day because it is unconstrained by current technological possibilities. The scenario starts with a description of how the nurse call system would be installed and caregivers would be trained. Next, a night in the life of Erik is described in which he makes calls, the caregivers use the system to ask for assistance and the novel nurse call system is used to ideally handle these situations. Next, Erik spikes a fever and a context call is generated and assigned. Erik is transferred to the hospital, where he also makes nurse calls to illustrate the use of the system in this setting.

Third, the ICT equipment needed to realize this scenario is described, e.g., the locator badges, temperature sensors, smartphones and call buttons. Finally, the white book describes the translation of the sunny-day scenario to a prototype implementation that can be technically realized. The architecture of the nurse call system and the user interfaces of the designed mobile application, as shown in Section II, are detailed.

The white book was evaluated and adapted together with the users at multiple occasions. The scenario was also used as a basis for several workshops. The evolution of the scenario was detailed in the white book with clear links to workshops and user interactions that triggered the changes and insights.

### *C. Decision-tree workshops*

The observations and the first version of the white book allowed to capture the scope, requirements and needed context information for the ambient-intelligent nurse call system. However, it was difficult to distill the decision process that caregivers propose or find ideal to prioritize and assign nurse calls. To resolve this, decision-tree workshops were organized.

At the start of the workshop, the participants described a complex situation involving nurse calls. Next, participants were asked to suppose they were an intelligent system that had a complete overview of the current situation. This system takes patient's nurse calls as input and is tasked with prioritizing and assigning the most appropriate caregivers to the call. The real life situations described by the participants were used to start the discussions by visualizing them, e.g. location of the patient, on a blue print of the work environment of the participants. To gather more context and make an informed decision, the participants asked questions. Instead of answering the question, discussions were first held about the importance of the requested info and possible answers the participants envisioned. This way the user researchers could tap into the reasoning made by the participants. The technical engineer visualized these questions on paper in the form of a decision tree. The order of the information in the tree reflects its importance, while the different nodes represent the parameters that should be taken into account to reach the ideal assignment.

It was determined that the assignment of caregivers to calls should depend on, in order of importance, the reason of the call, the competencies & roles of the staff, the priority of the call, the trust relationship and distance between the caregivers and patient and the current tasks of the staff. Consequently, several changes to the white book were made. Taking into account the roles, competencies and trust relationship was deemed much more important as the researchers perceived during the observations, while distance was deemed much less important by the participants. It was also assumed that a whole plethora of priority levels should be assigned to calls as this is usually the case in traditional nurse call systems. However, the participants claimed they only discerned between 3 levels, namely normal, urgent and very urgent. The latter category is preserved for life-threatening situations. Finally, participants also desired to redirect calls, easily get in touch with the staff member who redirected it and add information to a call, e.g., the reason which was discerned by contacting the patient.

Initially, the sunny-day scenario described the system as being able to determine the reason for a call based on the gathered context data. However, the participants perceived this as unrealistic, as such insight is achieved by years of experience and a deep understanding of the patient and situational context. They feared an unstable, incorrect and controlling system.

However, the participants did conclude that for assigning staff members to calls, 3 main reasons for making a call need to be discerned, namely hotel, caring and medical reasons.

Consequently, it was decided to not let the nurse call system determine the reason and the priority of the call. To replace this, the possibility to contact the patient, triage the call, assess its priority and redirect it was added to the mobile application. At this point the nurse call algorithm was split up in a simple algorithm to quickly assign calls to initial staff members and a second, more intelligent algorithm which is used after a call is redirected, as detailed in Section II-B. An algorithm was preferred above letting caregivers choose specific staff members to whom the call should be redirected. This is easier for inexperienced staff, frees caregivers from remembering who is currently available, increases the workload distribution of the calls and allows to take into account other context parameters when assigning calls. Finally, to better illustrate the benefits of using the ambient-intelligent nurse call system, the following features were added: generating context calls, adjusting the light level in the room based on the kind of call and presence of staff and unlocking the supply closet when a person with the appropriate competencies logs in.

### *D. Concept evaluation workshops*

The purpose of these workshops was to do some preliminary testing of the conclusions and changes that were made with regard to the white book and the ambient-intelligent nurse call system after the decision tree workshops before implementing them. Two types of workshops were organized. In the first workshop, the functionalities of the system were evaluated by participants with various qualifications, e.g., nurses, doctors, domains experts and designers. To illustrate the novel system, a movie was made of a specific part of the white book scenario, where most innovative functionalities were introduced. This movie was first shown in its entirety and then paused when elements were introduced that researchers wanted to discuss with the participants in smaller groups, such as the triage and the use of mobile devices. The second workshop consisted of individual usability tests of the preliminary interface design of the mobile application. The participants were presented paper prototypes of the interface. After a short introduction, the participants were asked to perform a task on the interface, without receiving instructions about the functions of the buttons. The participants were asked to talk out loud and explain what they did and thought that the symbols represented.

Both workshops resulted in useful feedback. The idea of call triage generated enthusiasm amongst the participants. The use of mobile devices caused some concern with regard to hygiene. There was some discussion whether the devices should vibrate or make a sound when a call came in, or if a mixed solution could be found. Also, there was a lot of discussion on how trust relationships should be integrated in the system. In addition, some participants found it difficult to redirect calls only to a certain "profile" rather than to a specific person. The usability tests led to some minor adjustments in the design of the user interface of the application, e.g., changing and moving buttons, adding feedback messages to indicate that an action was successful and translating the application into dutch.

### *E. User evaluation: embodied system use*

To achieve a deeper reflection on the novel ambient-intelligent nurse call system by the users, a prototype was implemented, as detailed in Section II, in the Patient Room of the Future (PRoF). PRoF is an intelligent patient room and adjacent hallway, realized in Belgium, aimed to make a patient feel more like home. For the prototype, RF tags and receivers were integrated to track the locations of the patients and staff. Temperature sensors were also available to monitor the temperature of the patients. The developed ambient-intelligent nurse call system was installed in PRoF and integrated with the available light control system, RF tags and sensors. Smartphones running the designed mobile application were also provided. This prototype allowed users to experience a fully immersed, more profound, contextual experience of the system in a lifelike context. After an elaborate introduction of the system, the participants were given context and persona cards. The context cards included instructions, which participants were asked to play out and resembled their professional activities. The persona cards identified the role they played, e.g., patient or nurse. In between and after the scenes, the participants discussed the system and mobile application with the researchers. During the first sessions, technical issues sometimes interfered with the role-play. These were solved and were no issue in the other sessions.

The evaluation resulted in a lot of recommendations that will be solved in future work. The way the trust relationship was integrated in the system was too rigid and decisive. Although the participants liked the idea of triage and redirecting the calls, some issues were noted. After redirecting a call, the caregivers sometimes felt the need to contact the caregiver who had finally handled the call to know how the problem was solved. Moreover, after a staff member had contacted the person who redirected a call, it was sometimes requested to be able to send the call back to this person. Also in this workshop, some participants had difficulty thinking of their colleagues in terms of their qualifications and felt the need to redirect calls to specific colleagues. Also, it quickly became clear that the smartphones should not only vibrate but also need to give an audio signal. Although some of these issues can be explained by the participants' current work practices, it also makes clear that extra attention should be paid to the adaptation of new work practices when the system is implemented in a real-life environment, since this might form a threshold for adoption.

## IV. Discussion

This paper illustrated how an interdisciplinary research team made an ambient-intelligent nurse call system in close collaboration with the users and stakeholders. An important lesson learned is that an intelligent system does not have to determine and solve everything as the users of the system are sometimes better suited to make decisions, e.g., triaging the calls. It became clear that a context-aware system in care should support caregivers and facilitate for instance data integration, but should also allow caregivers to overrule the system and have control over their work flow and environment.

Observations proved to be insufficient as user input. Only by repeatedly involving users throughout the design process, the researchers sufficiently nuanced their understanding of the users and their context to make a system that supports the users' daily work processes, without making them feel like they lost control. This is not to say that the described user involvement could not be improved. Although the final tests took place in PRoF, which was very close to reality, it was felt that a real-life setting could generate further insights. It will be investigated how a mobile set-up of the system can easily be tested in a real-life work setting. However, the varying available technology and networks make this a challenging endeavour. During the final tests, some technical issues popped up, which threatened to reduce the user tests to technical tests. Although these issues were quickly solved, it was sometimes hard to distinguish the participants' feedback on the system from feedback related to technical system failure.

Below the ten most important findings from the user-driven design process are summarized.

1) The novel nurse call system requires the users to think of their colleagues in terms of their qualifications and let the system redirect the call. The caregivers had a tendency of thinking of a specific colleague best suited for the job.

2) During workshops in the residential home, the trust relationship was regarded as a decisive element for assigning calls. However, it proved to be hard to translate this to an algorithm without creating too much side effects.

3) Early on it was decided that the smartphones should alert a call by vibrating to avoid noise overload. However, nearly all users in the final tests still requested a sound signal.

4) When redirecting a call, the user tests revealed that most participants like to know how the call was handled in the end as this gives them a sense of control and overview.

5) The users did not want the system to *dehumanize* their interactions with patients and colleagues. They liked that they could contact the patient after receiving a call.

6) Similarly, it was decided that the triage should not be done by the system, but by the caregiver talking to the patient.

7) The notion of distance had to be repeatedly discussed and reinterpreted. Based on the observations, the system was designed such that the caregivers would have to walk smaller distances. However, during the workshops, it became clear that other elements were considered equally important to dermine who should handle a call. As such, 'distance' became one of the parameters taken into account, rather than a decisive one.

8) While assigning calls more directly was seen as a big advantage of the system, participants noted that this implied losing an overview of what was going on at the department. Although this could partly be resolved through informal contacts, other general indications of activity will be needed.

9) Participants worried about implementation every time the system was presented as it require a new mindset and an alternative way of perceiving their colleagues. Moreover, care institutions have a lot of interns and a frequent change of personnel. This obstructs the adoption of new technology and functionalities. Given the additional fact that this system differs substantially from other systems and the current work practices, considerable attention should be paid to change management when implementing it.

10) An important challenge during all workshops was to explain how the system worked before any feedback could be gathered. In general, there was some discussion to what extent the users should understand the full complexity of the system when starting to use it. This is important to consider when looking at change management and implementation.

## V. Conclusion

This paper used an interdisciplinary user-driven methodology to design and develop an ambient-intelligent nurse call system and smartphone application. This way, the system is tuned towards the daily work processes, wishes and needs of the users. Moreover, the user-driven approach *humanizes* the system, increases its acceptance and makes the users feel in control. Future work will focus on incorperating the recommendations of the embodied user tests and investigating a way to create a general overview of the current situation in the department. Methods will also be investigated to easily test a mobile set-up of the system in a real-life setting.

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