Fast track article

Mobile health monitoring for the elderly: Designing for diversity

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Abstract

In the field of mobile health monitoring the current most important user groups are those aged 50+. In our project senSAVE® we developed a user interface for monitoring vital personal parameters that is specifically adapted to the needs of this group. The group is said to show less perception and control capability and has less experience in the use of information technology. More realistically, the group of 50+ users shows more diversity in their cognitive, sensory and motor skills than younger people. User interfaces for elderly people should therefore be designed for different capabilities and needs. For a mobile health monitoring system three design types were developed and evaluated in this study: three basic interfaces, two professional interfaces and an interface in between as a compromise of the two former types. Beyond monitoring the vital parameters of the user during mobile phases a stationary module for the inspection of aggregated data was included on a standard TV set together with a remote control device. The paper describes the user interface design and a comparative evaluation of the interfaces during and after the development, i.e. formative and summative evaluation. It also describes first user feedback about the stationary component.

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1. Introduction

There are several diseases that limit the ability of people to remain mobile or to control their own lives. Many people suffering from hypertension or other cardio-vascular diseases are in principle capable of leading a normal life as long as they are provided with indications of their vital data, which in the event of an emergency can be relayed to the emergency services. In this paper we present a system that provides a continuous health monitoring service for people with hypertension.

Hypertension is a widespread and often underestimated risk which has fatal long-term consequences. Successful therapy often requires a change of lifestyle, for example changing to a balanced diet combined with physical activities. Therefore, establishing awareness of vital parameters can positively influence and motivate people to pay attention to their own critical habits.

The diagnosis of hypertension is often complicated by two facts: first, even healthy people might have a dynamic and rapidly varying blood pressure; second, long-term blood-pressure monitoring tends to affect the quality of life. In the first case, variations result from multiple influences such as mental and physical situations (psychological strain, daytime, alertness and stress) or food patterns. In the second case, the fragmentary, uncomfortable, and annoying acquisition of vital parameters is incompatible with the normal way of life of otherwise healthy people – in particular incompatible with independent mobility.

Two services are described which allow continuous and context-aware access to the required information. First, a mobile setup collects the vital health data using an oxygen concentration measurement (found in the blood) and a set of ECG-sensors
that are woven into a shirt. The system then analyzes and transmits the data to a mobile device; this allows the user to view and interact with the data as required. Second, a standard TV-set allows the elderly user to inspect numerical or graphical summaries of the data for specific time periods or for unusual events. The combination of these two services goes beyond a mobile service on a dedicated portable device and includes access to the services from different places (inside or outside the home) while also supporting different needs (e.g. continuous ad hoc information and post hoc inspection).

Both of the services include a specific challenge. The first is to design a mobile device which is capable of receiving continuous data that can be easily retrieved and understood by the end user. The device should be small enough to be worn on a belt or in the pocket of the user while also being large enough to provide a readable display, accessible buttons and a means of output such as vibration, an audible alarm, or animation. The second is to design an interface for the TV device which is familiar to the elderly users, in this case through the use of a remote control. In this paper the services and their user interface design challenges are discussed.

2. Related work

Healthcare information systems are mostly designed for professionals to enter, receive and exchange information about patients. These systems include an increasing number of mobile devices to support health professionals ranging from a PC at their desk to a mobile device at the ‘bedside’ [1,2]. Methodological development issues in the context of health applications in hospitals for different professionals have been analyzed in [3,4]. Specific design aspects for different devices, including small mobile devices like PDAs and cell phones are studied, e.g., in [5]. The usability issues of such professional services have been studied in [6]. These authors adopted a user-centred design approach to the problem from the perspective of users in a hospital while taking into account the structure of the basic information units in a Hospital Information System (HIS) [6]. The user interface design illustrates several views of the patient data in terms of name lists, locations, medical parameters and navigation screens in two design iteration steps. The design was guided by the verbal and iconic vocabulary of the users that was examined in the requirement analysis and evaluated in the test phase. Note that the system was designed for the professionals in a hospital, not for the patients. The same is true for most of the other current mobile medical applications, e.g. [5].

Systems for patients, in particular for elderly patients, are more difficult to design due to their restricted perceptual competence and lack of training with interactive devices, and as people age there is a risk that they will start to use the devices improperly [7]. There are some examples of systems for the patients or non-professionals. One example is a self-monitoring application for people who are overweight [8]. This study compares a cell phone and a paper monitor; the results point a higher degree of monitoring by those using a cell phone. Other examples include an alcohol consumption monitor where electronic and paper monitoring were compared [9] and a dietary advisor [10]. However, none of these evaluated the user interface in any detail, but instead focussed on the feasibility, and the comparative advantage of the monitoring system was measured.

A project that supports medical treatment and behaviour of elderly people suffering from cardio-vascular disease is described in [11]. The system comprises a front worn array of body sensors, a user interaction system for displaying information and entering simple answers and a back-end system for professionals analyzing data and providing feedback and prompts to the elderly users. A “user friendly” GUI was developed for use on a PDA which uses large interaction buttons, short messages and data visualisations. While the results of the evaluations are not described the degree of acceptance is reported to be encouraging. In a subsequent paper from this project results of a formative evaluation consisting of 5 participants were reported. The paper concludes that users aged 65+ have problems understanding icons that use metaphors, and as a result explicit text presentations were chosen for the latest interface [12].

Mobile monitoring systems are often integrated into the underlying infrastructure. Complex or voluminous input and output of data is often more convenient and efficient when traditional devices such as a keyboard, mouse or screen are used. Therefore multi-device solutions are developed offering access to several devices adapted to the current context of use. In [5] an architecture is presented for local mobility in a hospital where PDA, laptop and desktop computers are interconnected via a Wireless LAN.

In contrast to the studies described before, focussing on professional users and on the functionality of the system, in this paper an application is described which is specifically designed for patients. It displays vital data continuously during mobile activities and displays aggregated data for inspection on a large screen. The interaction and information presentation design is the main focus of this paper.

3. Requirement analysis

3.1. Usability requirements and ease-of-use for the elderly

Though the risk of hypertension occurs in all ages, the biggest single group of sufferers are people aged 50+. Products for elderly users require an awareness of their individual needs. Therefore we undertook an analysis of the usability requirements specifically for this target group. Usability is a key feature of any technology and intuitive usability is of particular importance where users do not have a high degree of competence regarding technology or where training cannot be provided. Furthermore, it cannot be assumed that elderly people have an innate knowledge of information and communication technologies.
When compared to young people, elderly people are said to suffer from restrictions [see [13–18]]:

- loss of cognitive capacities
  - loss of memory and poor recall
  - few navigations skills or sequencing
- sight loss
  - loss of visual acuity
  - loss of near and/or distance vision
  - reduced field of vision
  - perception of colour, including age-related yellow vision
  - depth perception
  - speed of adaptation to changing light levels
  - sensitivity to light
- hearing loss
- decreased kinaesthetic ability
- less experience with and less confidence in interactive systems.

However this generalization does not reflect the entire truth: for example, elderly people are a group with more variety in their abilities than younger people [17, 18]. Furthermore, the 50+ generation consists of a vast array of different aptitudes, social status, training, experience and restrictions or impairments acquired or occurring during their lives giving rise to a diverse array of backgrounds and traits. Heller [19] called the older population “the dynamic diversity”. This big variety explains the limited chance for a successful “one User Interface for all” approach. In contrast to “design-for-all” [20] we must open up a “2- or 3-for-any” –philosophy that can reflect the diverse reality of the elderly population more appropriately. Therefore when addressing the wide age spectrum of the hypertension population it is obvious that beyond the characteristics of aged people there is also a need to consider the requirements of middle-aged or even younger people. If a single solution for all users is not appropriate then the spectrum of solutions should include at least one interface reflecting the perception and interaction limitations of elderly users as well as variant(s) reflecting the experiences and habits of younger users.

3.2. Devise requirements and device selection for the elderly

For a mobile device to be successfully adopted by users it must be wearable and unobtrusive, for example worn on a belt or placed in a pocket. We called this device a Wearable Base Station. The device should make use of wireless protocols so that it is able to receive data from the sensors, it should also process the data and be able to inform the user about their current health status. The device must also be able to store the data for a period of time before it is transmitted wirelessly to a server that we call a Home Base Station. In case of an emergency the data can also be transmitted wirelessly to what we called a Service Base Station which is used by service personnel who can initiate a course of action in case of an alert.

For the transmissions of data three types of connectivity were identified: Bluetooth for the body area network between the sensors and the mobile device, WLAN for the local area network between the mobile device and the local server at home and GPRS/UMTS for wide area network in case the user is outside in the city and needs a remote connectivity. Finally the device must be able to run an interface for users with a wide spectrum of reception and interaction requirements (see Section 3.1).

Because of a widespread use of mobile/smart phones, even in the group of elderly people (in 2005, 73% of those aged 55+ in Germany owned a mobile phone [21]), we decided to use a smart phone as the host of the Wearable Base Station. In addition we also examined which smart phones are available specifically for elderly users.

There are mobile phones especially designed for the elderly. Senior Phone [22] has big buttons but does not run specific health applications; Vitaphone 1100 [23] has three buttons but without text labels and only limited health display possibilities; Vitaphone 2300 [23] has only small buttons and a small screen. Other devices like the QBIC [24], the MCU [25], or the Medi-CliniQ [26] are too big for portable devices. Another identified problem with existing healthcare devices is the unsatisfactory information representation like the one used on the Palmtop Patient Monitor [27].

For the user’s mobile device we chose an MDA Pro for the Wearable Base Station. This device combines the connectivity functionality (Bluetooth, WLAN and GPRS) of a mobile phone with data processing and interaction functionality of a PDA. It displays current personal health information and allows direct interaction by stylus or via the user’s finger. As a future mobile device option we have developed design mock-ups for a wrist-health-phone (see Section 7), as a wrist device can be easily carried and used in a wide variety of contexts [28].

4. Design rationale for the development of user interfaces

4.1. Mobile device interface

Based on the heterogeneous characteristics and requirements of the health monitoring system our desire was to design simple and safe working interfaces and to ensure that the mobile device GUI was user friendly. During the requirement
Analysis and design cycles it became clear that a single solution would not fit the needs of all users. There are different needs and experiences and different habits in the population of people with high blood pressure that cannot be covered by one single interface. Thus for the elderly or for people with no experience and training with ICT we developed three basic interfaces with a dedicated application (senSAVE); this made use of limited presentation and interaction details. We developed two others called professional interfaces that were embedded into a standard set of applications that were designed for experienced PDA users. In this case senSAVE is used as an additional application which is integrated into the standard applications of the device. Also finally, we developed one interface that can be considered as a compromise between the basic and the professional interfaces that we called the advanced interface. This advanced interface has also got a big display and interaction elements similar to the basic interfaces. Compared to the basic interfaces it provides more opportunities for the user to explore the current health status and technical connectivity. Compared with the professional interfaces it is a stand-alone application not embedded into a set of applications.

For the professional interfaces the visual elements are designed as small interaction controls and presentation displays with several dialogue cascades. For the advanced interface, the interaction controls and presentation displays are prominent but not so large with only one dialogue level for the views relating to health and the technical parameters. For the basic interfaces the guideline was to reduce the complexity to the minimum and increase the usability to reflect the typical sensory and motor capabilities of elderly users. This basic interface group shows design characteristics that are recommended for elderly users such as:

- font sizes between 36pt and 48 pt [11]
- one-level navigation instead of using menu structures
- horizontal and vertical grid alignment of all used elements
- arrangement of the buttons at the bottom of the interface, so the input-hand would not hide the screen
- colour-neutral displays for visual impaired users
- redundant user guidance by colour-coding and blinking boxes
- slow animation speed, e.g. blinking rate.

4.2. Complementary stationary device interface

In addition to data which is constantly available while the user is mobile, aggregated data must be available. For this purpose a complementary component has been developed that imports the data from the mobile Wearable Base Station and displays an aggregation of data in terms of graphical and numeric tables. The data is displayed on a TV set connected to the mobile PDA via a set-top box. This component for more complex data inspection requires a larger screen and more convenient methods of interaction. For this we chose to use a standard TV set along with a remote control.

In the following section we describe the mobile application and the evaluation which we undertook. We then describe the stationary system and its evaluation.

5. The mobile senSAVE®-Prototype

The prototype of senSAVE® ("Sensor Assistance for Vital Events") was developed by a consortium of five Fraunhofer Institutes. The objective of senSAVE® was to contribute to the improvement of medical treatment for cardio-vascular diseases, thus increasing the quality of life for affected humans. The integration of the know-how of all partner institutes allowed the development of the medical components: (1) a set of long-life dry electrodes capable of being worn 24 h a day and 7 days a week without contact with the user’s skin, this compares favourably to wet electrodes that can only be worn for an hour or two before the skin gets red and itchy, (2) the mobile ECG-unit with dry electrodes enabling long-term ECG-observation, (3) the integration of the electrodes and the ECG-unit into a tailor-made sensor shirt reflecting the exact size and form of the user, (4) the plethysmography for the measurement of the pulse and (5) the oxygen saturation of the blood. Oxygen saturation is one of the indicators for the cardio-vascular status of a patient; today it is only known to some users. Using these indications the blood pressure can be derived via ECG, the pulse and the pulse wave transit time (PWTT) and can be heard from the pulse measurement location. This method allows a non-intrusive continuous estimation of the blood pressure without the need for an annoying periodic self-inflating blood-pressure sleeve.

One objective was that the target group should be able to use and understand the device. Furthermore, the prototype can be run on any mobile device that uses Windows Mobile 5 and that is able to read date streams in parallel from two Bluetooth channels.

5.1. Setup

Along with comfortable, easy-to-wear sensors that constantly measure all the necessary data and transmit them by Bluetooth to a PDA, the system also incorporates the software to collect and analyze the streams and to send them via the Internet or mobile network to a telemedical support centre, where trained staff can assess how critical the situation is, can advise patients over the phone (integrated in the MDA Pro), and can call a doctor if necessary.
Fig. 1. The web-based tool for medical support centres.

The PDA is the platform for the “mobile health assistant”. This assistant is responsible for calculating the blood pressure from the two data streams, it informs the user about current values and, if necessary, alerts the user in case of any discrepancy. The user always has the possibility to send the data to the health centre, which results in the doctor being called to interpret and respond to irregularities and changes in the patient’s cardio-vascular readings (Fig. 1).

5.2. Development methodology

Due to the complexities of supporting the desired user group which includes those with high blood pressure who may also be elderly we employed a User-Centred Design (UCD) approach combined with the Ease-of-Use approach [29,30]. ISO 13407 Human-centred design processes for interactive systems and ISO 20282 Ease of operation of everyday products provide guidance on human-centred design activities throughout the life cycle of computer-based interactive systems and especially with respect to everyday products; ISO Guide 71 extends the characteristics of the users to the group of the elderly. By adopting these approaches the development of the systems was closely linked to the real users.

The development approach includes cycles for specification, mock-ups, user feedback and refinements. The result of each single loop becomes an input to the subsequent loop; this approach should lead to a high match with the users’ needs. This evolutionary approach ensures that heterogeneous user feedback will be considered from the very beginning of the development until the end of the project.

For the development of the prototype we went through 3 major and some minor design and evaluation cycles. In the first phase, we developed the core ideas and functionalities and evaluated them with eight users from the intended user group of elderly people with the aid of Flash- and Paper-Mock-ups (first formative evaluation). In the second phase, we implemented a first user interface and evaluated the design and interaction with a second group of nine elderly users (second formative evaluation). At the end, we integrated all user feedback and finished the implementation of the final prototype which we then evaluated with 22 users (summative evaluation). In Section 5.4 we will show the results of the two preliminary evaluations. In Section 5.7 the results of the final evaluation are described.

5.3. Development of scenarios, use-cases and mock-ups for elderly users

Initially, we developed scenarios and a set of use-cases for a mobile patient with a cardio-vascular disease. The main set of use-cases included medical aspects such as checking current blood pressure, alerting the patient in case of critical values or communication with the doctor. Other use-cases addressed the technical use of the system such as checking battery power or being informed if the connection to the sensors failed. The third group consisted of cases where an emergency occurs and help is required.

For all use-cases we developed a set of Paper-Mock-ups each with a different look-and-feel. In order to test the interaction, we used a Flash-Mock-up that we installed on a mobile device. Due to the limited screen size of a smartphone/PDA (i.e. max. 640 x 480 px) it was likely that we would only have space for a limited number of interaction controls (2–3 buttons) combined with an information area of about one third of the whole space.

5.4. Evaluation of scenarios

In the first evaluation 8 occupants of an assisted living environment were interviewed (6 female and 2 male, in the age of 62–94 years), each were deemed to be people who would benefit from our system. More than half of those
interviewed said that the device should be as unobtrusive as possible, with the form factor of a watch being the preferred option.

For this user group, the display of blood pressure and pulse were of the most interest. Other parameters, such as oxygen saturation and ECG were not of interest to these users. Showing the blood pressure in numeric values was considered as the most useful. Most users were aware of their own blood-pressure value. They also liked to be able to view the pulse values; other parameters, such as oxygen saturation and ECG are of less interest for the users. Therefore the system should be able to display the values of blood pressure and pulse; annotation and animation were not required. The subjects also indicated that the system should use vibration and a sound for alerting the user in case of any abnormal value. The users also indicated that they would prefer a clearly audible alarm sound, even if other people also became aware of the alarm. The system should also support alerting the doctor by phone. In case of an emergency, the patients also indicated that they would prefer an emergency call. However it is noted that all parties involved indicated that any emergency alarm must be 100% reliable. For example the system must place a call when an emergency occurs as without an alarm there is a real risk to the user’s life, and conversely false alarms and calls would only serve to agitate the user.

5.5. Evaluation of user interface mock-up and prototype

For the evaluation of the interaction we developed a Flash-Mock-up running on an MDA Pro (Fig. 2). The interface mock-up on the screen consisted of three buttons for emergency call, phone and query/acknowledge. The test persons were able to use the graphical user interface and were able to understand the features.

From the results of the first evaluation phase we started to create a first running prototype. The prototype was connected to a (software-) simulator and did not use any hardware sensors. We used the prototype for a second evaluation with 9 persons (7 females, 2 males, 67–94 years old, 3 with past heart attack(s), 4 with hypertension; only one who owned a personal mobile phone). This evaluation took place in the same assisted living institute as noted earlier. The prototype ran on a T-Mobile MDA Pro in the size of 127.7 × 81 × 25 mm, weight of 285 g and resolution of 640 × 480 pixels.

At first glance, the users disliked the system because of the large and comparatively heavy device. They found the device to be uncomfortable and too complex to use. In order to check the input modality, we asked the users to start the calculator and to carry out some calculations. Right from the start all users were able to handle the system with the stylus or, more comfortably, with their fingers. However, all hardware buttons, particularly the scroll-buttons, were too small and too close to each other to be usable. However it was noted that after the initial familiarisation phase with the device the users become more open to the idea of such a system.

In the screen design (see Fig. 2) the placement of elements and the selection of colours, were accepted by all subjects. The text font was readable for most of the subjects and the health indicator in the centre of the screen was understandable for all subjects. Half of them used the colour indicator and half of them used the text. For the coloured background we adopted a traffic light metaphor indicating the current personal status; however most of the subjects did not realize this metaphor. The buttons were accepted in terms of size, colour and wording.

All users were able to read and understand their vital parameters except the oxygen saturation level which was not understood by five out of the nine users and regarded as being unnecessary by two more. More detailed information, e.g. the profile of parameters during the time interval, were not considered to be helpful. Only one person was able to use the sequential flow (“Verlauf”) of technical indicators at the bottom of the display (see Fig. 2). Eight out of nine subjects either had timing problems (i.e. the data display changed too quickly) or problems in understanding the wording of Connection and Sensors.

For comparison reasons a smaller device was shown to the subjects, i.e. a T-Mobile MDA Compact, with a size of 108 × 58 × 18, weight of 150 g, resolution of 320 × 240 pixels. About half of the users preferred this device because of its smaller size and weight. On the other hand we found that with the smaller display (and therefore smaller interactive
elements) the other half of the users did not feel as comfortable in operating the device as they had before. However we acknowledge that the final version of the software should be able to operate on a range of devices, therefore GUI elements should be scalable and not of fixed size so that they display correctly on each device.

5.6. Design alternatives

The design of the user interfaces reflects the requirements to be simple and robust. Several alternatives were developed and tested during the formative evaluations in order to uncover their strengths and weaknesses. Based on the results of the pre-study (see 5.5) 6 variants were developed for the summative evaluation (see Fig. 3). The 6 interfaces were developed using the following design rationale:

The basic interface variants have a full screen-mode for the health application. The interface versions basic and basic plus provide only the options to switch between technique and health parameters. The basic interface contains only indicator names and numerical values. The basic interface plus contains additional icons and value annotations. The sequential interface shows a sequential display with 7 “Forward/Backward” steps.

The advanced user interface consists of 3 parts: in the centre there is a display of the current vital parameters or technical conditions of connectivity and energy status; below, an icon bar indicates the technical and health status through the use of green/red colours which blink in case of abnormal values. On the bottom of the advanced interface there are 2 buttons to navigate through 3 screens: health, technical and clock. (Additionally, there is a password-protected menu for the doctor to set up personal limit values for the various medical parameters.)

The professional interface versions show the integration of the application into the operating system for experienced PDA users. One version uses cascading menus for the interaction between the different views; the second version provides an icon bar for the interaction.

5.7. Summative evaluation of design alternatives

The evaluation aim was to identify the usefulness of the service and the usability of the user interfaces including the information presentation, interaction method, and how understandable the medical vocabulary was and the alert announcements in critical situations. The evaluation was designed to obtain feedback about the preferences between the design alternatives. Note that the assumption was not to identify one best interface but to identify interface versions for different user groups.

The summative evaluation test session included a demonstration of the six user interfaces and test tasks for the users. The objectives were identifying whether the subjects could use the system and obtain the information they required. For the evaluation of the identifiability and understandability of the health status information the subjects had to interpret a number of given health values. For the evaluation of the navigability the subjects had to find a specific value which at the outset was not displayed on the screen.

The sample of the test users included 8 female and 14 male persons: 18 persons suffered from high blood pressure, 4 had other cardio-vascular diseases. Because high blood pressure is also relevant to younger patients, the ages ranged from 36 to 79 with a median of 60 years. Within the group 17 had prior experience of using a computer, 17 had used mobile phones and 5 had used pocket PCs (PDAs).

For the evaluation of the 6 user interfaces a questionnaire was developed. The questionnaire included quantitative parts to assess the information presentation according to ISO 9241 part 12 and a qualitative part to assess the understanding of the content of the information and how to navigate the information space according to ISO 9241, part 10.

5.7.1. Evaluation of the information presentation

The subjects were asked to assess the information presentation of each of the six interface variants. Three aspects were asked about the information presentation (translation of the German questions):

Fig. 3. Thumbnails of user interface variants.
• “Is the display clearly arranged?”
• “Is the display readable?”
• “Are the colours convenient?”

The answers of the subjects encompassed three grades: 1 = very good, 2 = rather good, 3 = not good. The results of the 22 subjects are shown in Fig. 4. The figure shows the assessment of the information presentation of the six interface versions both for the three individual aspects: arrangement, readability, colour convenience and a mean score of the three elements.

Both the basic and also the advanced interfaces received very positive results for information presentation. The positive assessment score for the information presentation of the basic interface is not surprising because this interface displays a reduced amount of information. However the advanced interface with more complex information presentation also received very positive scores. Thus, both interfaces were acceptable from the information presentation point of view. Also the basic plus and the basic sequential interfaces received positive assessments, with ratings between very good and rather good. In the case of the professional interfaces the subjects found the information presented too small and complicated with results not exceeding “rather good”.

5.7.2. Feel of the interface: Interaction design

The aim of the interaction design process was to reduce the interface dialogue steps to a minimum, with relevant information being available in as few steps as possible. Two types of information had to be conveyed to the users, three health parameters, e.g. the blood pressure, the pulse and the oxygen concentration of the blood; and three conditions of the technical components, e.g. the energy state of the battery, the oxygen concentration sensor connectivity and the ECG-sensor connectivity. One of these groups of information can be read at a glance, the other group of information is displayed only after clicking on the respective button.

• “Try to display... (e.g. the state of the ECG-sensor)’’

The first task of the evaluation incorporates a user initiated dialogue: the user is assumed to receive information from the application. The results of this task for the six interface versions show (see Fig. 5) that most of the subjects could solve the task to select specified information; only in the case of the sequential interface version did half of the subjects display problems when navigating through the information space. The results also show that at least in the case of the advanced, the basic and the basic plus interface versions most of the subjects understood the displayed information. For the other three interface versions, i.e. for the basic sequential and for the two professional interfaces the interaction style and the information content are less clear.

• “What would you do in response to this system behaviour?” (Warning)

The second task of the evaluation incorporates a system initiated dialogue: the user receives a warning event by a blinking icon. The results show (see Fig. 6) that more than half of the subjects for all interface versions correctly responded to the blinking icon by clicking on it. More than half of the subjects of the advanced, basic and basic plus interfaces also understood the meaning of the blink icon as an alarm indicator.

5.7.3. Overall ranking of the interface variants

Following on from the test task the users were asked to rank the user interfaces according to presentation and interaction features (see Fig. 7).
The advanced interface with a full senSAVE\textsuperscript{®} display which did not make use of any other applications but which contained several display and interaction features was ranked as number one by half of the subjects. The second place went to the basic interface with only two buttons for technical and health parameter values and only plain displays of the parameter names and the numeric values of the parameters, i.e., without icons and without annotations in the case of critical situations (such as those found in the basic plus interface). For the rest of the alternative interfaces the number of proponents was very low; one or even zero. The basic interface plus with additional icons and annotations in the case of critical situations was ranked as second by five subjects.

Our findings point to there not being one interface-for-all, instead it points to there being two main interface preferences:
the advanced interface for users with an interest in the details relating to each parameter including animations (blinking of icons) and annotations (words interpreting the indicator values) and capable to understand system behaviour as prompts to interact with the user interface;

the basic interface for users who would only like to see an overview of their health status without any details.

These two interfaces are acceptable from the information presentation and interaction points of view. The two alternative basic interface versions show no advantage compared to the simple basic interface. However the professional interface may be interesting when more people are familiar with a PDA for daily use.

5.7.4. Additional user evaluation results about naming, icon and animation features

In addition to the overall evaluation of the 6 user interfaces and their comparative ranking more qualitative details were asked about the interaction with the advanced user interface. The names of the health parameters and the technical elements were identical for all interface variants so that we could concentrate on the interface itself. We wanted to know if the subjects could understand the wording and how they would respond in the event of an alarm.

5.7.4.1. Understandability. First we asked the subjects about the understandability of the wordings and indicators used for the parameters. The result is shown in Fig. 8.

All subjects understood the wording used for the blood-pressure and pulse parameters, however the wording of the oxygen concentration in the blood was understood by only 5 out of 22 subjects — oxygen concentration seems not to be a known health indicator (see also 5.4).

The subjects were also asked whether they understood the icons illustrating the normal state of the system and the current health indicators. While all subjects understood the battery status only half of them understood the display elements relating to the connection of the ECG-sensor or the oxygen concentration sensor. Most subjects understood the meaning of the values for blood pressure (except 5) and pulse (except 7) while the value of the oxygen concentration was understood by less than half of the subjects.

5.7.4.2. Icon displays. Another part of the study involved asking people if they could interpret the icons and animations used for the health indicators (see Fig. 9).

More than half of the subjects preferred the use of icons to display information. The remaining half was undecided or indicated that they did not like icons. The icons were designed to let people get a quick impression of the state of their health (health icons) or the state of the system (functional icons). However the users need to be trained to ensure that they understand the correct meaning of the icons. Once the users have learned the meaning of the icons, i.e. the icon colour (green or red) and the icon behaviour (blinking), it is expected that they will be able to understand and use the system.

5.7.4.3. Understanding the alarm. Providing timely and accurate alarm is a key element of any monitoring system. For example, it is important that the system is able to alert the user to any medical or technical issues. Furthermore it should also be able to communicate the problem effectively. More than half of the subjects understood that when the device vibrated that at least one of their health parameters was out of the acceptable range. However almost half of the subjects associated the vibration with something else, e.g. a measurement is currently active or a measurement is currently not in operation. Furthermore, almost none of the subjects found the use of vibration annoying. However many comments indicated that the vibration was too poor and that it should be used in conjunction with an auditory alarm.

Half of the subjects prefer a combination of vibrations as an alarm followed by an acoustic signal (see Fig. 10).
The vibration is used as a discrete signal before the acoustic alarm arouses the attention of those in the wider social environment. The comments also point to the necessity for people to adapt the alarm according to individual, social and physical conditions. For example some people are hearing impaired and require stronger/progressive acoustic signals or non-acoustic alternatives and other people start to panic when an acoustic alarm sounds.
5.7.4.4. Activate buttons of the display. As shown in 5.7.2 most of the subjects managed to activate the buttons of the display without any problems; 3 subjects had problems in identifying the touch sensitive areas of the display — in particular with respect to buttons and visual icon areas with blinking periods during alarm events. Almost all of the subjects managed to activate the button of the display via the stylus without problems; only 1 reported a problem. Beyond this main result 3 subjects found that using the stylus was too cumbersome. Almost all of the subjects managed to activate the button on the display by a finger without any problems; only 1 subject reported problems because the button field was too small for his finger.

5.7.4.5. Switching between the display modes of the application: Health, technical and clock. The interaction design of the advanced interface contains three screens relating to health, the technical components and a neutral display of clock. Almost none of the subjects had problems clicking on the Technics button when accessing the battery power display; only one person showed an interest in this feature when his battery power approached zero. Although four people experienced no problems finding the information, all four had problems interpreting the displayed values e.g. does 3:36 h mean this is the amount of power left or the amount of power consumed. All subjects understood the icon of an empty battery; two thirds understood that they should charge the battery soon, while three found the icon for the empty battery but did not know what it meant. Almost all of the subjects, except 1, had no problem in finding out the display date and time. Six subjects expected more services beyond the date and time information after clicking on the Clock button.

5.7.5. Final overall assessment of the mobile service

At the end of the evaluation the subjects were asked to assess the acceptability of the system with the advanced interface together with the hardware device (an MDA Pro). The results are shown in the Fig. 11. Three-quarters of the subjects could imagine wearing such a system and using it continuously. Only 3 could not imagine using it. One could imagine using the system at least in limited periods of feeling ill. Comments show that the size of the device (MDA Pro) is not convenient and obstructs sports activities. While one subject indicated that continuous monitoring could drive the client crazy. Positive comments were made with respect to the alarm function as it alerts the user to any critical changes without the need to provide them with continuous updates.

Almost half of the subjects preferred the big size with a big display and the other half preferred a smaller device with a smaller display. Two subjects indicated that they would prefer a wristwatch similar to the one developed during the mock-up phase.

Nearly three-quarters of the subjects had no problem with their data being visible or audible to others in social settings, whereas one-quarter was opposed to this idea. This points to the importance of considering social aspects when designing such interfaces.

6. Stationary system component for the post-inspection of data

In this part of the paper we describe the stationary counterpart of the mobile service. While the user is mobile, the mobile service measures his or her health status and processes the data stream for deriving medical values. The data forms the basis for continuous ad hoc information display for the mobile user. The values can also be delivered to the medical service centre for real-time intervention in case of acute danger.

During the mobile service the user reads the value snapshots from the display. For a comprehensive inspection of the health condition (diagnosis) and for medical treatment (therapy) more than one snapshot is needed. Although the data is monitored and stored continuously by the MDA it is sent at regular intervals to the stationary system. The stationary system allows the user to store and retrieve long-term data which may be useful in understanding the meaning of single values or long-term patterns. It can also be used to view the effect of events, external factors or medical treatments.

For this post-inspection a PC tool, designed to display aggregated data on a TV-screen, allows elderly users to make use of their own TV set. A study by [31] indicates that interactive TV applications are very likely to be widely adopted by elderly users as they are already familiar with their TV and do not need to purchase additional equipment such as a computer. Based on the results of preliminary tests with seniors we developed a software tool for visualisation of numerical health values in a tabular form and in a time-value diagram. For the data input and control of the system behaviour we analyzed the appropriateness of a standard TV remote control. Compared to a standard PC a TV together with a set-top box and a remote control has disadvantages with respect to user effectiveness and efficiency. For example the screen resolution is often better on a PC and the methods of interaction are often easier. Therefore the question cannot be put in terms of asking if a set-top box is better than a PC, but rather if such an approach is good enough for users who have very limited or none experience of computers and/or who do not own a computer equipment at home.

In this section we identify the best practices for the design, illustrate our final design of the application, and describe our evaluation of the use of such an application by seniors.

6.1. Examination of guidelines for information presentation

Setups with personal computer, monitor and mouse have achieved a dominant position in the design of commercial computer systems and applications. Little is known about the specific attributes of computer systems connected to a TV-
screen. At present, only some guidelines exist for the development of such a system for our group of target users. Due to the lack of substantial knowledge we conducted preliminary user tests to find out the requirements for this kind of device.

6.1.1. Technical setup

As a first step we conducted a small study in a senior citizens home with seven seniors and found that the screen size (diagonal) was between 49” and 69” (with an average of 64”). The distance of the users to the TV-screen ranged from 2.2 m to 3.2 m (with an average of 2.5 m). With these tests we figured out that when compared to a computer-screen the TV-device used by most of the participants (i.e. a cathode ray tube, CRT-screen) has limited performance regarding colours, resolution and image definition.

6.1.2. Our design guidelines

The following collection of our basic design principles is the result of the analysis of colours, lines, interspaces and fonts that has been uncovered by our preliminary tests with small groups of seniors.

"Physiologically, light text on a dark background is easier to read. The ocular receptors are then triggered by the characters rather than the negative space around them ..." [32]. However, using contrasting colours, pure black and white is problematic on a television screen. For testing colours we presented screens of multiple colours to three seniors on their home TV-screen. Although the brightness and contrast varied on the different TV-screens, the rendering of the colours was acceptable. In our tests, contrasting colours on a dark background were considered tiresome and also reduced readability. Readability was found to be much better on a white background, but the seniors did not feel comfortable with high brightness. We have therefore used orange or grey background colours (in two levels) and black, white or turquoise fonts.

The use of lines, in particular parallel lines of time-value diagrams for post-inspection, requires specific consideration on TV-screens. When testing screens using horizontal and vertical lines (illustrated in left and centre images of Fig. 12) and rectangles, three seniors noticed differences in the sharpness of the lines, flickering of the whole output, and colour drifts (particularly for vertical lines). Horizontal lines of widths below 4 pixels and interspaces below 12 pixels were flickering on all three screens. Vertical lines were displayed perfectly on one TV; but had heavy defects on the other two, where lines with interspaces below 6 pixels were flickering in violet colour (see right image of Fig. 12). Displaying non-parallel lines, e.g. rectangles, were perceptible for the seniors already from a line width of 1 pixel. The interspaces between lines seem to be more relevant to perceptibility of the user interface than the line width.

In another test, we asked seven seniors for feedback about the readability of text and coloured icons. We presented screens with text in different sizes, and icons such as an apple, banana, or ball in varying image sizes. Readability of text was confirmed by all elderly users from a size of 30 pixels. We decided to use the non-serif-font Arial with a size between 30 and 54 pixels. Readability of diverse icons, such as tree and ball, was confirmed for a minimum size of 60 \times 60 pixels. Other icons were not correctly identified by some seniors regardless of their image size, e.g. a (red) apple was considered a cherry, or the banana was identified as lemon. This supports the requirement of using distinguishable colours for different icons.

6.1.3. The final user interface

These guidelines have been applied to the final design of our application. The final look-and-feel of the presentation is exemplified in Fig. 13. To ensure that our presentations are not overfilled with information or otherwise stressful, we adhere to the guideline of [33]: “Ideally, a single screen should contain a single ‘message’ or single ‘activity’. Because all tested persons were German, we used German language for all texts, labels and values.

Several innovative navigation approaches are introduced in [34], e.g. the carousel or flipper. In this study, people favoured the carousel design because of its simplicity, ease-of-use, and ability to provide guidance through the navigation tree. We decided to use the approach of a standard selection menu, where users can scroll up and down each item by pressing corresponding buttons. The left image of Fig. 13 shows the main menu (“Hauptmenü”) of five options, i.e. add blood-pressure value, change user, add user, view graphical presentation, and view tabular presentation. The centre image shows the graphical presentation of blood-pressure values for a single day (i.e. from 6 am to 12 am of August, 9th 2006). The right image shows the specific values in tabular form as numerical data of time (“Uhrzeit”) and value (“Wert”).

Fig. 12. Test screen for horizontal lines, vertical lines, and output with colour drift.
As expected, the test of the presentation counterbalanced the influence of limited eyesight and the low resolution of the TV-screen. Two persons with low vision and one with an eye cataract had problems reading it. The people had no problems when viewing it at a computer monitor but sporadic problems when doing so at a TV-screen. This shows the difficulty of compensating for the limited resolution and the long distance of the user from the TV-screen, e.g. by applying a design of big fonts and bold lines.

One of the main incentives which help motivating seniors to use technology is to provide them with a simple, intuitive, and easy-to-use interface [31]. In parallel to appropriate appearance (look) of the user interface, a critical issue is the interaction (feel) with the system and careful consideration must also be given to the control device intended for using the system [33]. Available options for controlling the application and entering data are either a wireless keyboard and mouse, or a TV-like remote control. Common guidelines for (computer) keyboards such as those presented in [35] recommend a minimum size of keys of 12–15 mm, and interspaces between the centres of two keys of at least 18–20 mm. For commercial remote controls, size is a major concern, making the application of such recommendations to small handy devices impossible. Also because standard PC recommendations cannot be applied for remote controls, the main objective of the evaluation was to find out whether such a device is a usable tool for seniors.

The next section will describe the evaluation of the input device. For detailed description of the development of our requirements and the evaluation of the information presentation the reader is referred to [36].

6.2. Evaluation of a remote control for a TV-based eHealth application

This section describes the final evaluation of the use of a remote control (Microsoft MCE Remote Control) as an input device for an interactive eHealth application designed for a TV-screen.

6.2.1. The remote control

The input device of our system is a TV-like remote control from Microsoft. The operation of such devices is well known to a broad variety of people. In contrast, elderly users are less familiar with input devices for computers such as mouse and keyboard.

Originally, the remote control was delivered as an input device for the Media Center Edition of Microsoft’s Windows XP operating system (see the left image in Fig. 14). The control provides a large number of hardware keys available for interaction. In order to avoid overloading our users we restricted the design to only make use of the navigation-arrows including the OK-button for selection/confirmation (see the upper right image of Fig. 14), and the keypad for entering numbers and text (see the lower right image of Fig. 14).

6.2.2. Sample

The test group consisted of eight seniors, seven female and one male with ages ranging from 74 to 92 years. All users had limited visual capabilities and suffered from far or short sightedness, cataracts, macular degeneration or were blind in one eye. All subjects except one had some typewriter experience, three had computer experience and four had at least minimal mobile phone experience.

6.2.3. Execution of the study

For the evaluation, we compared the remote control and TV design with a standard computer and monitor setup. The subjects used both systems but the order in which they used them was assigned on a random basis. With both combinations of input devices the seniors were asked to:

- enter a given numerical blood-pressure value into a selected input field
- enter their name into a text field using the keyboard or the triple-tab of the remote control
- navigate to several sub-pages and then return to the main menu.
For switching between the several screens we used two versions of navigation: navigation with menus and navigation with buttons. In both cases the user navigates the focus to the desired item and activates the item using a specific action. In structured menus, all items are listed top-down and the user moves the focus up and down in the menu (cf. left image in Fig. 13). When using buttons, the items are placed at specific positions on the page where the user would employ all four navigation buttons to select the desired item. At the bottom of the middle and right images of Fig. 13 there are two buttons for navigating back to the last page ("Zurück", left on the bottom line) or the main menu ("Hauptmenü", centre on the bottom line).

During execution of the tasks the evaluator documented all problems and errors by the user. In addition, we measured the task completion time. After finishing the task, the users were asked for their personal opinion of each input device and asked whether they would use it in future. Due to severe muscle deterioration problems person 8 was unable to complete the tasks but provided valuable personal feedback.

6.2.4. Results

All users were able to enter their blood-pressure values. Four used the computer keyboard faster than the remote control; however they were also experienced computer users. Whereas two people used the remote control more quickly, the person with computer, typewriter and mobile phone experience set the absolute fastest time (using the computer keyboard) and in addition the second fastest time with the remote control. In summary, a traditional keyboard could be more efficient for experienced users — however none of the users had any problems using the remote control for this task.

Due to seven out of eight users having used typewriters, they had also no problems in entering their names with the keyboard. When using the remote control, all except one understood the operation of the triple-tab element, i.e. to press the same key several times to enter a character at the next position in the labelling list of that key. Analyzing the error rate we detected weaknesses with the remote control. For example, four out of seven users entered the wrong text because of the inadequate labelling of the keys (labelling below the key instead of above the key, cf. lower right image of Fig. 14). Additionally, the delay before switching the cursor to the next position needs special attention. Due to several key presses required, three out of seven seniors were too slow in finishing before the focus switched to the next element.

The remote control had a clear advantage when it came to letting the users navigate through the menus. With the computer mouse, all except three users (two of whom are computer experienced users) needed extensive support (three persons in more than half of the navigation steps, one even for 5 steps out of 6). Using the remote control, two persons did not need support at all, four persons only once, and one person for the first two navigation steps. Overall, navigating through menus seems to be more intuitive with the remote control and easier to learn.

Whereas all persons were able to navigate using menus, none of them were able to navigate using buttons without support; three persons needed up to three supporting actions (in a row of eight navigation steps). Even if the navigation to
the item was not the problem, the activation itself was. Four out of seven people required support in more than half of the cases.

6.2.5. Acceptance

At the end of the test, all seniors stated feeling comfortable with both setups of input and output devices. Three persons noticed that they were not able to operate the combination mouse/keyboard well. One would like to have bigger labels at the keyboard and a bigger mouse pointer at the monitor. There was no negative comment on the computer monitor at all.

The remote control was partially accepted, the main criticisms concerned the shape and labelling of the specific device. One person explicitly mentioned the font size of the labels; additionally two disapproved the small size of the keys. The placement of the OK-button in the middle of the navigation switch was seen as inappropriate. Two persons had negative comments with respect to the TV as output device, addressing the distance (too far away) and the screen size (too small display).

6.3. Conclusions for the stationary TV-setting

In our study of the TV-based information inspection we included only a small sample of subjects to see whether principally the components and methods of information presentation and navigation work for elderly people. The results are encouraging, showing that the participants were able to finish all tasks successfully in an acceptable way. The remote control is usable in particular for navigating through menus; it is also an acceptable input device for entering numbers and short texts.

If a personal computer with monitor, keyboard, and mouse is available it will be used more effectively (less errors) and efficiently (less time) in particular for experienced users. We realized that seniors are generally perfectly able to control a computer application with either of the input settings, however they required sufficient time in order to learn how to do so.

Where alternative equipment is not available in the elderly person’s home we have found that using a remote control for interaction can provide a successful alternative option. However, there are some restrictions with the latter option, for example, the design of the remote sometimes caused problems or resulted in failed operations. This would point to the need for re-designing the remote control in order to make it more accessible for elderly users.

For future work on the use of the remote control as a pervasive input device for seniors, we need to carry out an additional evaluation with a larger sample group. Therefore, assuming such changes are made we can assume that using a remote control would provide a successful alternative to using a computer where the latter is not an option.

7. Conclusions and future work

In the senSAVE® project we developed a mobile system to monitor vital parameters. The user interface and the interaction were specifically adapted to the needs of the elderly. In this paper we described the development of the system and the outcome of an evaluation.

Almost all of the people in the evaluation sample suffered from severe high blood pressure or from other cardio-vascular diseases so that the evaluation was performed with a sample of people who had experience and awareness of the health problems that the system aims to address.

In the tests we studied the presentation of information, the guidance provided by the dialogues and the alarm function. The results pointed to two of the interfaces providing the necessary levels of usability. The first of the preferred user interfaces, the advanced interface, is characterized by displays of graphical symbols and animations which contain the possibility to check parameter values. The second of the preferred interfaces, the basic interface, is characterized by a simple navigation style through two different screens with an expressive display. It highlights critical values by blinking the background boxes used in text labels. The advanced interface is more complex than the basic version where only two display options present basic data for health and technical parameters.

We cannot assign one of the two alternatives to a specific group of subjects, i.e., old versus young, computer experienced versus no computer experience. Therefore we assume that either both versions will be enhanced in a next development step by optimizing strengths and weaknesses or by letting users decide which version they would like to use. In addition to usability aspects the users were asked if they would make use of it in their daily life. Three-quarters of the subjects said they would use the service. They would also use this device overtly, not hiding it as a health monitoring system by displaying a neutral application like time and date as a default display.

In general, the basic interface is the solution for those users who want less information and the simplest interaction. The advanced interface is suitable for people who like to have visual icons for the status of the health and for the technical components. A further test has to show, if in contrast to elderly or technically inexperienced people, younger people with PDA experience are more interested in the professional interface version, discreetly integrated in the operating system.

From the requirement interviews we learned that users would prefer an unobtrusive system. Their most favourable device would be in the style of a wristwatch. In parallel to the application development we also conducted studies to explore the usability of a wristwatch design. This work found that a wristwatch combining the 3 main functions e.g. emergency, phone/service and health values was the most desired option. One of our three copyright-protected designs is shown in Fig. 15.
The mobile setup of equipment and application design based on the MDA is central to the idea of such a system being continuously used. We have shown that in order for seniors to make use of such a system it must be able to show both numerical and graphical aggregated data. The tests have shown that a standard PC with keyboard and mouse can be operated by seniors and that a standard TV with a remote control device can be operated with acceptable effectiveness and efficiency. The decision to use a standard TV with a remote control or a more traditional computer approach depends on the environment in which the equipment is used combined with the level of user experience. Further tests using more advanced hardware and bigger and more heterogeneous samples have to be conducted. In particular, tests on continuous usage of the system components, integrating mobile phases and stationary phases in realistic environments have to be performed.

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