User Interface Development of a COPD Remote Monitoring Application

A User-centred Design Process

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***Abstract*—The Norwegian Health sector is undergoing changes at all levels due to recent health reforms. Services traditionally offered by specialized health care are being transferred to primary health care managed by municipalities. In this context, telemedicine technology is introduced to facilitate new services that support communication across local borders, optimizing resources and increasing cost effectiveness. This study focuses on the user-centred design, iterative development and evaluation of the user interface of a mobile application to be used in a new telemedicine service for remote monitoring of chronic obstructive pulmonary disease symptoms. The research is a result of the cooperation between a municipality and a hospital as part of the European Commission project United4Health. Through a user-centred design approach, the tablet device application was developed based on information gathered in a workshop and group interviews where the end-users, patients and health professionals, described their preferred way of interacting with the telemedicine technology. User evaluations reported positive results on the ease of use and user satisfaction with the interaction with the application. Iterative application's user interface refinements were made through several end-users' evaluations, resulting in a fully developed system suitable for remote monitoring.**

Keywords-remote monitoring; patient empowerment; usability evaluation; telemedicine; user-centred design.

I. Introduction

The Norwegian Coordination Reform [1] urged health organisations to implement structural changes as the ultimate citizens' health care providers. Services traditionally offered by specialized health care national and regional institutions (e.g., follow up of chronic diseases managed by hospitals) were transferred to primary health care managed by municipalities. This new situation brought to light the need for an effective coordination and improved communication across borders of health care services.

Services associated with the new patient pathways required from municipalities an effective and efficient use of Information and Communication Technologies (ICTs). In this context, the European Commission funded research project United4Health [2] is developing technology for remote monitoring of chronic diseases and communication across the different levels of health care services. The Norwegian contribution to the United4Health project focuses on technologies that support remote monitoring of chronic obstructive pulmonary disease (COPD) patients after hospital discharge. The aim of the project is to evaluate the benefits of using technology for monitoring COPD patients that traditionally did not have the possibility of reporting their symptoms and health status after hospitalisation. Potential benefits would include reduction of hospital readmission rates with their correspondent diminution in cost, and benefits of quality of life improvements (already being investigated in other ongoing research from the same project). Research evidence shows that COPD patients are at an increased risk of readmission to hospital within 12 months [3][4] after hospital discharge.

In this study, a mobile telemedicine application was developed in a tablet device for remote monitoring of blood oxygen saturation (SpO_2) and pulse measurements. In addition, the application contained a questionnaire for daily report of COPD symptoms. Patients took measurements at home that were wirelessly transmitted to a newly established telemedicine centre assigned by a municipality partner where health professionals would remotely attend the patient.

A user-centred design (UCD) process was employed for the development and evaluation of the mobile telemedicine application. The application was designed with the active involvement of end-users from patient's union of cardiac and pulmonary patients, health professionals from the municipality and partner hospital. The study was led by a research group with ICT and health background. The application was validated from an operational and qualitative usability aspect. The research questions (RQs) of this study were:

RQ1: "How can a telemedicine application be developed for remote home monitoring purpose, including COPD patients and disease-related health professionals?"

RQ2: "What lessons from this study are transferable and applicable for the development of technology useful for other clinical pathways?"

Following this introduction, Section II gives an overview of research background about UCD and Section III outlines the research methodology employed. Section IV describes the results of the mobile application development. In Section V, the results are discussed and in Section VI the conclusion and future work are presented.

II. Research Background

UCD involves end-users in all the stages of a system's development [5][6][7]. It helps to understand users' needs and the context of use, which are key elements for the construction of a system framed within a clinical workflow [8]. In addition, the usability evaluation is necessary to analyse user's interaction and user satisfaction with the system [9][10][11]. Telemedicine systems often involve the interaction between multiple user groups through a system, e.g., a patient at home communicates using a device with nurse in telemedicine or health centre, or with general practitioner (GP) at his office. Communication in these scenarios of use is usually multimodal, that is, synchronous (e.g., videoconference) and asynchronous (e.g., data transmission and dispatch), what makes it crucial to know between whom, how and when the information transmission and personal contacts occur. Thus, an effective telemedicine application requires a detailed analysis of end-users' needs to inform system designers. In addition, the usability of such application is crucial for the continuous, efficient and satisfactory use of an application [7].

III. Methodology

The design of the telemedicine tablet application was performed as a part of the research project United4Health [2]. Qualitative methods were used for data collection and analysis. The UCD process was divided into two phases, as illustrated in Figure 1: (A) workshop with representative end-users, such as patients and health professionals; (B) iterative design of the tablet application for COPD remote monitoring. The latter was formed by a set of four sub-phases: design and implementation, functional test, user evaluation, and field trial. Each sub-phase's output informed the input of the next. The iterative system development included a sequence of concatenated stages where user requirements informed the design, implementation and functional test of the application.

Running commentary gathered in the two phases of the UCD process resulted in 18 hours of audio-visually recorded data, verbatim transcribed by the researchers. Transcripts were coded into categories and a qualitative content analysis [11] was made with the software QSR NVIVO v10.

A. *Workshop with End-users*

A one-day workshop with end-user representatives (i.e., health professionals and patients) was set up in October 2013 hosted by the University of Agder, Norway. The aim was to understand the context of use and to gather user requirements for the design of the tablet application for remote monitoring. In addition, the workshop was a source of information and familiarisation for end-users with the research team and health personnel working in the project. The participants were two members of the union of cardiac and pulmonary patients, mean age of 69 years; two nurses from the municipality and hospital, mean clinical experience of 6 years with COPD patients; and two technicians from hospital responsible for correct functioning and maintenance of the tablet devices, with a mean of 6 years of experience working

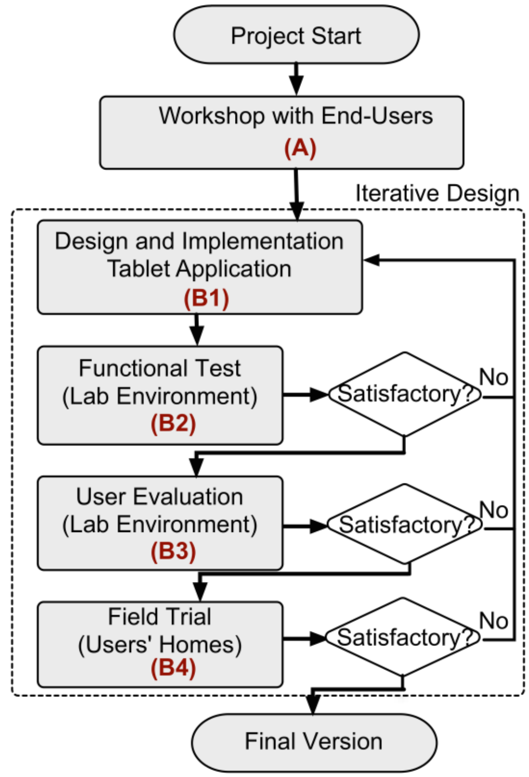

Figure 1. The User-Centred Design Process.

with medical technical equipment.

The workshop lasted 5 hours and was divided into two parts. In the first part of the workshop, participants were given an introduction to the research project United4Health. In order to understand the context of use of the system, a prototype demonstration of wirelessly transmitted measurements of SpO_2 and pulse was shown to end-users on a tablet. Additionally, a video-conference (software Cisco Jabber Video for Telepresence, v4.2) between a patient and a health care professional was tested. COPD patient representatives described their preferred way of interacting with the application at home and suggested ideas for the user interface's (UI) layout. Participants used colourful post-it notes and handmade sketches to describe application's functionalities and design.

In the second part of the workshop, participants described the workflow of remote monitoring of a COPD patient, such as taking measurements at home, transmitting measurements' values through the system to the telemedicine centre and illustrating the feedback given from telemedicine centre to COPD patient at home.

B. *Iterative Design*

The design of the application was carried out through the iterative execution of the following stages: design and implementation, functional test, user evaluation and field trial. A development team supervised by one of the researchers developed the system. An interaction designer hired by the team was in charge of the initial graphical user interface and interaction design.

1) Design and Implementation: The results from the workshop led the initial design and implementation of a Java native application. Java includes libraries for several low-level Application Program Interfaces (APIs), in particular for the Bluetooth connectivity and communication with sensor devices. In addition, using Java allowed the application to be used across different tablet devices. The outcome of the latter sub-phases informed additional user requirements included in the implementation of the User Interface Design (UID) and system's functionality.

2) Functional Test: The facilities of the Centre for eHealth and Healthcare Technology of the University of Agder, Norway, were used as a test bed for a functional test of the implemented application. It allowed to verify whether the system matched the requested functionality determined by users in the workshop and in user evaluations from other iterations.

3) User Evaluation: Two evaluations of the application's prototype were carried out with end users in the Usability Laboratory at the Centre for eHealth and Healthcare Technology, in January and February 2014. The facilities had two separate test rooms (referred to as "test room 1" and "test room 2") and one observation room. The infrastructure is further described in [12]. The user evaluations had the aim to provide end-user's feedback to the development team about system's errors and potential refinements. They consisted of a series of tasks using a think aloud protocol [9][10]. Group interviews were made at the end of the evaluations to complete the feedback.

a) Evaluation 1: 15 health care professionals from the municipality and hospital partner constructed a role-play scenario. In test room 1, which represented patient's home, health care professionals simulated the patient's use of tablet application and, at the same time, the interaction with the health care professionals placed in test room 2, which represented the telemedicine centre. The functionalities tested at a patient's home consisted of taking and sending patient's measurements (i.e., SpO_2 and pulse) and filling and sending a questionnaire to the telemedicine centre. In addition, a videoconference session between the patient and the telemedicine centre was performed and evaluated. There were three repetitions of the scenario with different users and the overall duration of the evaluation was 6 hours.

b) Evaluation 2: The evaluation was performed as a role-play with a simulation of the proposed use scenario of the new telemedicine application. It was carried out two weeks after evaluation 1 and included 9 end-users: 2 members of the patient's union (played the patient's role), 3 nurses from municipality (played telemedicine centre health professional's role), 2 nurses from hospital and 2 technicians from hospital. The test simulated the following interactions with the application: 1) user training of COPD patient in hospital with instructions from a hospital nurse; 2) COPD patient at home taking measurements, filling in questionnaire and sending it to the telemedicine centre; 3) videoconference between COPD patient at home and a health professional at the telemedicine centre. There were two iterations of the user evaluation, with a total duration of 5 hours.

4) Field Trial: A field trial was carried out with 6 diagnosed COPD patients (mean age 72.6 years). They tested the continuous functioning and interaction with the technology at home during a period of 7 days. The trial lasted 5 weeks. Each user made daily measurements, filled in a questionnaire and sent them to the telemedicine centre. In addition, videoconference between a user and a health professional at the telemedicine centre was tested. All these tasks were performed using a tablet device.

After each week of testing, user suggestions were incorporated in the improvement of the system.

IV. RESULTS

The results were obtained from transcripts of the audio-visually recorded data and annotations and observations during the UCD process. To ease the reading, the results of each phase are separately presented.

A. Workshop with End-users

The contributions from end-users in the workshop are grouped in 3 different categories: context of use, UID and patient workflow.

1) Context of Use: Patient representatives explained that individual's level of physical energy is regularly low and even simple actions, such as using a tablet device, may seem unachievable. This issue underlined the importance of designing an easy-to-use application that did not require much effort to be successfully used. Therefore, it was suggested that user interaction with the system must be minimal, with only the few necessary actions. One of them stated: "Usability is extremely important for the interaction with this application since COPD patients have little energy left on bad days".

2) User Interface Design: Patients agreed with the authentication method through a Personal Identification Number (PIN) mechanism, although they expressed having difficulties remembering numbers and they preferred to be able to choose their own PIN instead of using a pre-defined one. In addition, they requested to have the user's name at the top of the home screen after successful login.

Patients required seeing the results of their own measurements on the device's screen before sending them to the telemedicine centre. In addition, they asked for receiving immediate feedback when measurements were successfully delivered.

A time-span visualization of several days of measurement results was also suggested where patients could see measurements from previous days.

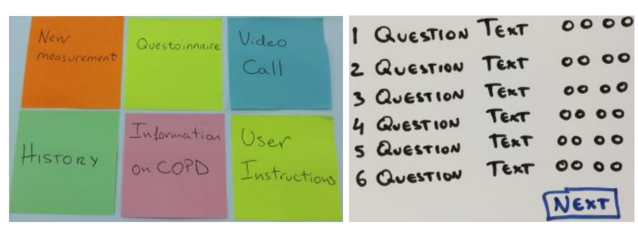

Figure 2. User's UI suggestions (left) and questionnaire's sketch (right).

Another request was the possibility of simultaneously seeing videoconference professional was required to guide the patient through any of the tasks.

For the interface's layout, patients chose not to have nested menus (e.g., one patient representative said: "you cannot ask elderly people to remember what is inside each menu") and instead, one touch area per action. Suggestions included 6 squared big-size touch areas, with readable and appropriate function's names. The 3 most important functions were placed at the top: "new measurements", "daily questionnaire" and "videoconference". The other 3 touch areas with less frequently used functions were placed at the bottom: "historical data", "information about COPD", and "user instructions", see Figure 2, left.

Further, it was concluded that the system was not to be used for emergency situations, so a written text saying "Call 113 for emergency" was required to be shown in the system's interface.

The answer to the daily questionnaire was suggested to be of multiple touchable selections (see Figure 2, right), and to have six questions visible on the screen at the same time because patients were afraid they would get tired of reading the questions one by one.

3) Patient Workflow: One of the most important findings of the workshop was the setup of the COPD patient's workflow for the use of the telemedicine application for remote monitoring, see Figure 3. In addition, instructions were required to be concise, to be on paper and digitally available in the system.

It is a common practice in the telemedicine centre to differentiate patient status by an easy-to-interpret colour scheme, called triage. Triage colour was represented in this case by a green colour for measurement values within the pre-defined cut-off values; and yellow and red ones for attention and alert respectively, activated when measurement values are outside the cut-off values. Patient representatives initially suggested that patients at home should be able to see the triage colour related to their own measurements in order to have a feeling of control of their own health. However, a "false" red measurement (e.g., cold finger can alter measurement readings) could potentially increase patient's anxiety. At the end, patient representatives agreed with the option that only health care professionals could see the triage's colour.

B. Iterative Design

1) Design and Implementation: In the sub-phase Design and Implementation, workshop's results were transformed into the initial Graphical User Interface (GUI) outline, see Figure 4, and user requirements of the application. Outcomes from further iterations' sub-phases contributed to refine the user requirements and improve the application implementation.

2) Functional Test: In each of the iterations, the application had to go through functionality test run by the development team. The identification of errors at this stage

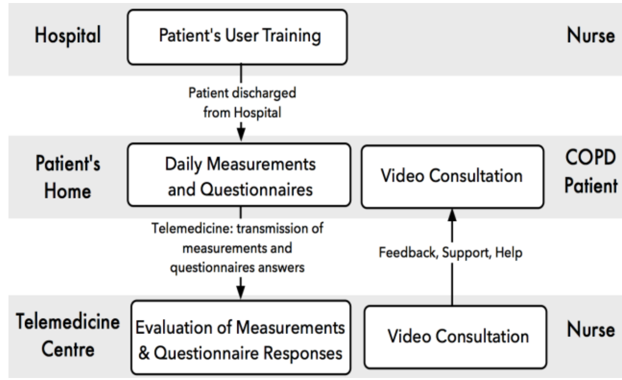

Figure 3. COPD patient workflow in remote monitoring.

proved to be relatively cost-effective to fix in terms of time and effort compared with further sub-phases.

3) User Evaluation: User evaluations in laboratory settings concerned the display of the questionnaire with the adequate number of questions per screen, from 6 to finally 1 to ease individual reading. A questionnaire's answers review was included to allow patient to double check before sending. Initially, a progress bar notified data transmission but it was insufficient for distinguishing between successful and unsuccessful data delivery. Therefore, a feedback notification pop-up window was included with text, a round face and a status colour code (green smiley face for successful delivery and red sad face for unsuccessful one).

In addition, user manual needed to be incorporated in the system, with intuitive images to guide on how to handle the measurement devices step-by-step. In this line, the GUI corresponding to the new measurement was improved by removing the unnecessary information load to perform the task. For instance, while measurement reader device showed correct measured values, wrong ones were displayed in the tablet screen and sent to the telemedicine centre. User evaluation helped to identify this issue.

In the group interviews, user comments about the tablet use were overall positive: "I think this will help us if we get worse; the tablet was easy to use with 5 or 6 functions and few things that should be touched to do measurements".

Some comments referred to the need of user training: "With some user training I think most people could use this, it was not complicated. If you forget how to do it, you can contact telemedicine centre". Patients also positively commented about the videoconference: "It was a good feeling to have videoconference with telemedicine centre. I think for users at home, it is good to see and hear the nurse".

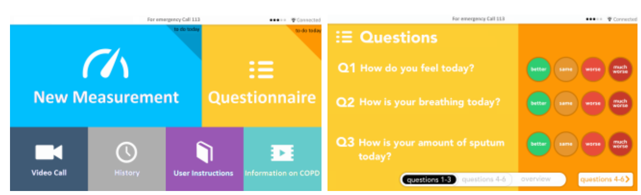

Figure 4. GUI of tablet application and the questionnaire.

4) Field Trial: Field trial results included automatic start of the application due to problems with touch initiation of the program icon (equivalent to mouse double-click). It was found that, ideally, the tablet application should report the battery level of the measurement device to the telemedicine centre and user. The videoconference image and sound quality was improved through software configuration changes. Furthermore, the sound quality was improved by the selection of optimal headphones and microphone setup for the users. All participants gave positive feedback about the printed user manual. In particular, they stated that the text was easy to understand and the pictures accurately illustrated what to do for each task.

Users' overall rating of the application was satisfactory concerning all interactions with tablet (equipment setup, device connection, measurements, questionnaire filling, data transmission, and videoconference): "I think the application is very well designed so you do not misunderstand anything. I consider this system user-friendly"; "This application was easy to use, because even an old person like me without computer experience could use it".

C. *Final Version*

The UCD process resulted in a tablet application that was evaluated as "satisfactory" in all sub-phases. A number of exemplary screen shots of the application are shown in Figure 5. The UI screenshot on top shows the main screen of the application, from where the user can initiate the main functions, such as "new measurements" and "questionnaire". The blue screen on the bottom left shows the start screen for carrying out new SpO_2 measurement, while the orange screen on the bottom right shows parts of the UI for the daily questionnaire. This application is being deployed on the trial devices of the Norwegian part of the United4Health project, and will support the new remote monitoring services provided by the municipalities involved.

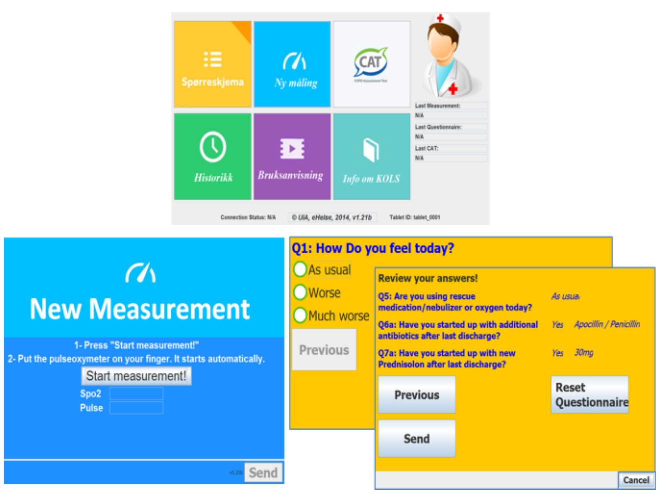

Figure 5. Screenshots of the system's final implementation.

V. DISCUSSION

In this paper, the UCD process for the development of a tablet device application for remote monitoring of patients in home environment has been presented. A typical telemedicine application involves multiple users in number and type, such as patients, health professionals and administrative officers. This is why the involvement of those groups of end-users in the design of a new technical application is crucial to understand the clinical workflow where the solution will be deployed, its context of use and the interactions involved. The two research questions (RQs) formulated at the beginning of this paper are answered below based on the results from the study.

About the RQ1, which asked about the development of a telemedicine application for remote monitoring, it has been demonstrated that a UCD approach successfully included the user (i.e., COPD patients and health professionals) needs in the development of the application. For it, a workshop efficiently outlined user needs, context of use, and helped user groups to familiarise themselves with each other and the research team. In addition, the workshop established a useful starting point for the system's application development taking on board different kinds of user requirements, as aspects of GUI, interaction and functionalities.

The user evaluation was carried out both in a laboratory environment and at users' homes. The early evaluations in laboratory environment simulated a realistic user scenario in a controlled test environment, and enabled users to give feedback about GUI design and the interactions following the remote monitoring process. The field trial allowed studying the long-term and real-time usage of the technology by users at their home.

Several lessons were learned during the study that can be transferable for technology development for other clinical pathways (RQ2) involving chronic conditions included in the projections of global mortality for 2030, such as ischaemic heart disease and diabetes [13]. In particular, solutions to be installed in medical environments necessarily need to firstly involve all the user groups in the creation of the solution, and secondly, analyse how this solution can best fit in an existing clinical workflow or, if non-existent, build up such workflow in collaboration with the end-users. It is known that interoperability issues are one of the main problems nowadays in the deployment and use of technology in medical environments. In this way, the inclusion of a field trial provided useful information about the interactions between humans and technology, but also between the different technologies involved.

The research study of the UCD process had also some limitations such as a reduced number of end-users and user-scenarios were tested in a simulated environment. However, the simulated test environment allowed to create highly realistic scenarios under controlled conditions, and the field trial gave the opportunity to test the system in real-world settings.

VI. Conclusion and Future Work

This study has been developed including end-users' (i.e., COPD patients and health professionals) needs, suggestions and preferences, in the design and evaluation of a COPD remote monitoring application. Positive results were reported after evaluation in laboratory settings, regarding ease of use of the telemedicine solution and user satisfaction. The continuous refinement of the application was the key to fully develop the system suitable for remote monitoring of COPD patients.

The benefits of giving the opportunity to COPD patients to report symptoms and health status after hospitalisation, together with actively including them in building the solution, are in line with the European Union (EU) Health Strategy, *"putting patients at the heart of the system and encouraging them to be involved in managing their own healthcare needs"* [14].

These facts, together with the simulation in high fidelity laboratory settings, and the field trial are significant contributing factors to the ecological validity of the research here presented. In a world where human-computer interactions progressively increase in number and complexity, real-time evaluations in real-world settings become crucial to understand not only the successful deployment, but the efficient and continuous use of technological solutions.

The proposed UCD process has been validated by the development of a telemedicine tablet application, successfully adopted by the 7th Framework Programme for Research and Technological Development (FP7) EU project United4Health, which focused on technologies that support remote monitoring of COPD patients after hospital discharge. As a result, over 200 patients in various municipalities in Norway will use the application.

In terms of future work, it is proposed to address research on appropriate identification and authentication methods for patients, more autonomous reasoning and decision support in the application, and integration of further devices to support other patient groups and clinical pathways associated with chronic diseases, such as hypertension and diabetes.

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