

# User-Centered Design of a COPD Remote Monitoring Application

## Experiences from the EU-project United4Health

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**Abstract**—Recent health reforms in Norway have produced changes at all levels of the health sector, bringing to light a need for technology solutions explicitly designed for enhancing end-user collaboration. Telemedicine technology can support in this context new services that enable communication across local borders, optimizing resources and increasing cost effectiveness. This study focuses on the user-centered design, iterative development and evaluation of the user interface of a mobile application for a new telemedicine service for remote monitoring of chronic obstructive pulmonary disease patients. The tablet device application was developed based on information gathered in a workshop and group interviews where the end-users, e.g., patients and health professionals, described their preferred way of interacting with the telemedicine technology. User evaluations showed positive results on the ease of use and user satisfaction regarding the interaction with the application. Application's user interface refinements were made iteratively through several end-users' evaluations, resulting in a fully developed system suitable for remote monitoring of chronic obstructive pulmonary disease patients. Furthermore, the process led to the deployment of a telemedicine system, adopted by the partners of the project United4Health as part of the 7<sup>th</sup> Framework Programme for Research of the European Union.

**Keywords**—user-centered design; telemedicine; software development; usability evaluation.

### I. INTRODUCTION

Health care services involve heterogeneous user groups, such as health professionals, administrative employees and patients. However, these groups share a common need: easy-to-use systems that support collaboration and coordination between users. User-centered design (UCD) has proven to be an effective methodology to identify needs across different user groups and to include them in the implementation of information and communication technology (ICT) systems [1] while increasing the usability [2] [3] and user satisfaction of clinical systems.

In Norway, a recent health reform [4] urged health organizations to implement structural changes and new pathways for citizens. Services that traditionally were offered by specialized national and regional health care institutions (e.g., follow-up of chronic diseases managed by hospitals) were transferred to primary health care managed by

municipalities. This service responsibility shift brought to light the need for an effective coordination and improved communication across borders of health care services [5][6][7], where ICT could play an essential role.

The prevalence of chronic diseases is increasing and chronic obstructive pulmonary disease (COPD) is predicted to be the fourth most fatal disease globally in 2030 [8]. COPD patients suffer from exacerbations with frequent admissions to hospital, leading to a reduced quality of life [9] and an increase of medical expenses for the society [10]. In this context, the 7<sup>th</sup> Framework Programme for Research of the European Union (EU FP7) funded the research project United4Health [11], to develop technology for remote monitoring of chronic diseases and communication across the different levels of health care services. In particular, the Norwegian contribution to the United4Health project focused on the development of telemedicine technology that supported remote monitoring of COPD patients after hospital discharge [12]. Research evidence showed that COPD patients are at an increased risk of readmission to hospital within 12 months [13][14] after hospital discharge. In the Norwegian health system, municipal health care services are responsible for patients after hospital discharge, which requires a close collaboration with general practitioners (GPs) and specialists at hospital to provide continuity of care for patients with chronic conditions. The aim of the project was then to evaluate the benefits of using ICT for monitoring COPD patients that traditionally have not had the possibility of reporting their symptoms and health status after hospitalization. The potential benefits would include reduction of hospital readmission rates with their correspondent diminution in cost and benefits on quality of life.

Two developments were made connected with the U4H project: a mobile telemedicine application for continuous monitoring COPD patient's symptoms and an information system (IS) for the new telemedicine centre through which health professionals would remotely attend the patients [1][15]. This paper presents the development of the mobile telemedicine application on a tablet device for remote monitoring of blood oxygen saturation (SpO<sub>2</sub>) and pulse measurements. In addition, the application included a questionnaire for daily self-evaluation of COPD symptoms. Through the application, patients were able to take measurements at home that were wirelessly transmitted to

the telemedicine centre. In order to achieve acceptable levels of effectiveness, efficiency, and satisfaction, a UCD process led by a multidisciplinary research group with ICT and health background was employed for the development and evaluation of the mobile telemedicine application. The application was designed with the active involvement of end-users: patients from the patient's union of cardiac and pulmonary patients and health professionals from the municipality and partner hospital. The results from the UCD and evaluation process of the mobile telemedicine application were validated from operational and qualitative usability perspectives. The following research questions (RQ) were addressed:

RQ1: "How can a mobile telemedicine application for remote monitoring of COPD patients be developed with the contribution in the design process of patients and disease-related health professionals?"

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

Following this introduction, Section II gives an overview of the research background about UCD. Section III outlines the research methodology employed and 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

Telemedicine can be defined as a remote electronic clinical consultation using technology for the delivery of health care and the exchange of information across distance. Telemedicine covers a diverse spectrum of technologies and clinical applications [16][17][18]. Telemedicine has the potential to improve the equity of access to health care services and, therefore, the quality of the health care [17]. Mobile technology is used nowadays for multiple purposes in health, such as monitoring diseases and personalized management. Portable devices allow collection of data from patients and electronic data transmission over the Internet. Mobile networks support interactive communication between health care professionals and enable remote direct feedback to the patient. These uses are targeted at improving long-term cost-effectiveness, real time monitoring, shortening feedback's time and reducing the number of hospital visits [19].

Telemedicine systems often involve the interaction between multiple user groups through a digital system, e.g., a patient at home communicates using a device with nurse in a telemedicine or health centre, or with GP at their office. Communication in these use scenarios 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 communication occur. Thus, an effective telemedicine application requires a detailed analysis of end-users' needs to inform system designers and the usability is necessary for the continuous, efficient and satisfactory use of an application. In system development, the approach of UCD [20][21][22][23]

involves end-users in all the stages and 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 [24]. In addition, the usability evaluation allows to analyze user's interaction and user satisfaction with the system [25][26][27].

UCD has already been used in health contexts. For instance, Martínez-Alcalá et al. [28] presented a study of telemedicine systems' development based on UCD. The aim was to develop two intuitive and efficient systems, with an optimized design of the user interface (UI) according to users' needs. The eMental System and the e-Park System development was composed of four phases: analysis, design, implementation and evaluation. They concluded that researchers and system developers must work together to integrate the knowledge of UCD towards new systems customized to users' specific needs. Further, they identified 4 research lines: (1) deployment of other telemedicine systems based on their framework including other technology; (2) development of tailored versions of a telemedicine system for mobile devices; (3) implementation of their approach in the treatment and rehabilitation therapy file; (4) incorporation of intelligent agents in telemedicine systems to support the patient and medical staff.

Ho et al. [29] described the application of a UCD process of a new remote consultation system for use in developing regions with methods such as semi-structured interviews, participant observation, and focus groups. Paper prototyping was used in the initial iterative design. De Vito Dabbs et al. [30] described the UCD of a Pocket PATH, a handheld PC that allowed lung transplant patients with data recording, messaging and decision-support to promote self-care and communication to their transplant team in hospital. The UCD process is described with the use of an interdisciplinary team in order to understand the patient users. Representative patients were recruited for meaningful selection of tasks and participation in platform for development. The evaluation was carried out in laboratory settings to measure usability, and afterwards, completed by an assessment of the functionality through a field study. Das et al. [31] used a co-design approach to involve users in the design process. Users were COPD patients that explored mobile technologies to support their health condition and disease. The examples listed above show the importance of user participation from the early stage of designing a technological solution. However, many studies like these did not reach final deployment stage. The contribution of this paper is a case study with a UCD process of a COPD remote monitoring application describing all the stages of design, whose final result has been deployed in real settings.

## III. METHODOLOGY

Qualitative methods such as observations and group interviews were used for data collection and analysis during the UCD process of the telemedicine tablet application, which was framed within the research project United4Health [11][12]. The UCD process was executed in two phases with a total duration of 6 months during 2013 and 2014. The process is described 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. Each sub-phase's output informed the input of the next. The iterative system development included a sequence of four concatenated stages: design and implementation, functional test, user evaluation and field trial.

The running commentary gathered during 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 through a qualitative content analysis [27] with the software QSR NVIVO v10 [32].

#### A. Workshop with End-users

A one-day workshop with 7 end-user representatives (e.g., patients, health professionals and technicians) was hosted by the University of Agder, Norway. The aim was to understand the context of use and to work out the user requirements for the design of the tablet application for remote monitoring. In addition, the workshop was a source of information and familiarization for end-users with the research team and health professionals working in the

project. The participants were 2 members of the union of cardiac and pulmonary patients, mean age of 69 years; 2 nurses and 1 project-leader from the municipality and hospital, mean clinical experience of 6 years with COPD patients; and 2 technicians from hospital responsible for correct functioning and maintenance of the tablet devices, mean of 6 years of experience working 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. A prototype demonstration of wirelessly transmitted measurements of SpO<sub>2</sub> and pulse was shown to end-users on a tablet device to facilitate the understanding of the context of use of the system. Additionally, a videoconference between a patient and a health care professional was tested. The members of the union of cardiac and pulmonary patients described their preferred way of interacting with the application at home and suggested ideas for the UI's layout. The participants used colorful post-it notes and handmade sketches to describe application's functionalities and design.

In the second part of the workshop, participants described their suggestions for the procedure 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 a 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 subsequent 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 Health Care Technology of the University of Agder, Norway, were used as a test bed for a functional test of the implemented application. It allowed verifying whether the system matched the requested functionality determined by users in the workshop and in user evaluations from other iterations. Performance and scalability of the system were not within the scope of the functional test.

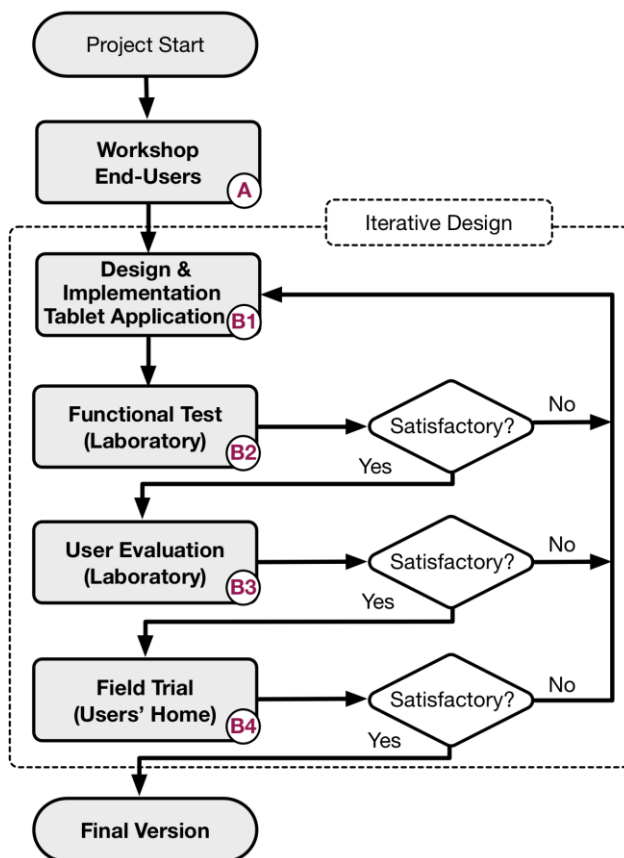


Figure 1. The User-Centered Design Process.

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 Health Care Technology. 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 [33]. 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 [34][35][36]. Group interviews were made at the end of the evaluations to complete the feedback.

a) *Evaluation 1*: In total 15 end-users participated in the first evaluation. They were: 13 nurses and physicians from municipality and hospital partner and 2 technicians from hospital partner. During the test, the participants were involved in a role-play scenario. In the patient's home (represented by test room 1), health care professionals simulated the patient's use of tablet application (see Figure 2). At the same time, the telemedicine centre (represented by test room 2) contained the health care professionals that interacted with patient's home. The functionalities tested at a patient's home consisted of taking and sending patient's measurements (i.e., SpO<sub>2</sub> and pulse), filling and sending a questionnaire to the telemedicine centre. In addition, a videoconference session between the patient and the telemedicine centre was evaluated. There were three repetitions of the scenario with different users. The overall duration of the evaluation was 6 hours.

b) *Evaluation 2*: The second evaluation included another role-play with the new telemedicine application. It was carried out two weeks after the first evaluation and included 9 end-users: 2 members of the patient's union (who played the patient's role), 3 nurses from municipality (who 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 symptom self-evaluation 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.



Figure 2. End-user testing the tablet application during the evaluation.



Figure 3. The remote monitoring equipment.

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 was performed across several weeks, lasting 5 weeks in total. Each participant was equipped with a suitcase including a pulse oximetry device (Nonin Onyx II, 2012) and a tablet device (Lenovo ThinkPad tablet 2, 2013, Windows 8.1) with the telemedicine application installed. In addition, an adjustable USB camera and a headset were included for the videoconference. Figure 3 shows the remote monitoring equipment. Every day, the participants used the tablet application for measurements with the pulse oximetry device filled in the symptoms' self-evaluation questionnaire. The data were sent over the mobile network to the telemedicine centre. A videoconference session between the participant at home and a health professional at the telemedicine centre was tested in addition.

All these tasks were performed using the tablet device. After each week of testing, the research team visited each

participant at home and made a user evaluation of the application and an interview. The user evaluation entailed switching on tablet, logging in to the telemedicine application, taking measurements, filling in symptom self-evaluation questionnaire, sending the data to the telemedicine centre and answering a videoconference call from the telemedicine centre. The interviews focused on the user experience and suggestions for further improvements. The users' suggestions in the field trial were incorporated in the iterative refinements of the tablet application. More details on the field trial are presented in [37].

#### IV. RESULTS

The results were obtained from the content analysis of the 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, user interface design and procedure for remote monitoring.

1) *Context of Use*: Patient representatives explained that their individual's level of physical energy was regularly low and even simple actions, such as using a tablet device, might become unachievable. This issue underlined the importance of designing an easy-to-use application that did not require much physical effort and mental workload to be successfully used. Therefore, it was suggested that user interaction with the system must be minimal, with only the few necessary actions. One participant 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 each successful login. Patients required seeing the results of their own measurements on the device's screen before sending them to the telemedicine centre. 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. Another request was the possibility of seeing the health professional through a videoconference to simultaneously 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, only 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



Figure 4. Users' suggestions for the UI of the tablet application's main screen.

"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 4. Further, it was concluded that the system was not to be used for emergency situations, so a written text was displayed that said "Call 113 for emergency" was suggested.

For the questionnaire, end-users suggested multiple touchable selections for the daily self-evaluation of symptoms. Specifically, 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 (see Figure 5). The button to navigate to the next step, labelled "Next", had to be visible at the bottom of the screen. The users requested to be able to review the questionnaire answers before sending the self-evaluation questionnaire.

3) *Procedure for Remote Monitoring*: One of the most important findings of the workshop was the description of the procedure for the use of the telemedicine application for remote monitoring of COPD patients.

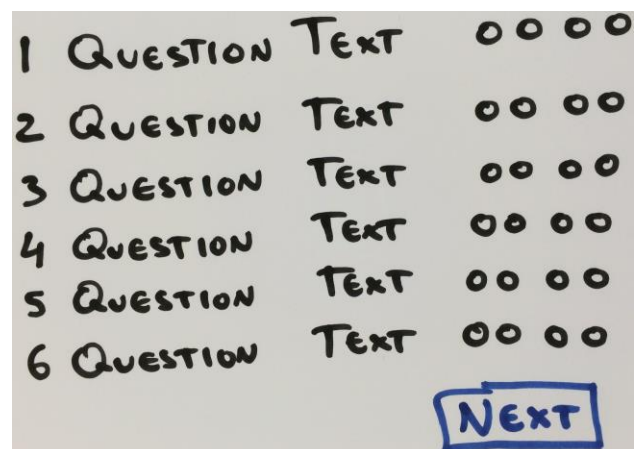


Figure 5. User's UI suggestions for the questionnaire for daily self-evaluation of symptoms.

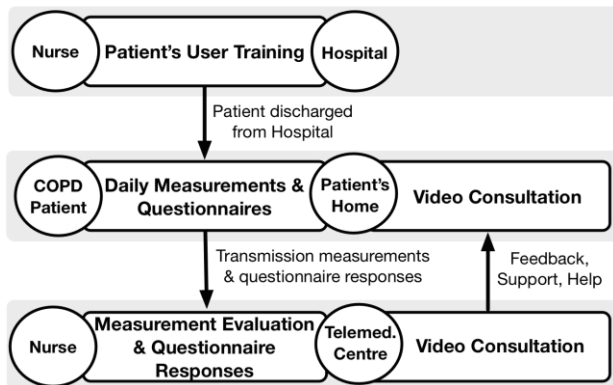


Figure 6. Procedure for remote monitoring.

Figure 6 shows the end users' suggestion for the process and feedback in the remote monitoring scenario. In addition, instructions were required to be concise and to be additionally available on paper and through the system.

It is a common practice in a given telemedicine centre to differentiate patient status by an easy-to-interpret color scheme, called triage. Triage color was represented in this case by a green color for measurement values within the predefined cut-off values; yellow color for requiring attention and red one to trigger alert. Yellow and red colors were activated when measurement values were outside the predefined cut-off values. Patient representatives initially suggested that patients at home should be able to see the triage color 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 may 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 color.

### B. Iterative Design

The contributions from the iterative design are presented following the sub-phases of design and implementation, functional test, user evaluations and field trial.

1) *Design and Implementation:* In the sub-phase design and implementation, the workshop's results were transformed into user requirements. The initial graphical user interface (GUI) for the main screen of the tablet application was outlined including the two functions "New Measurement" and "Questionnaire", which were placed at the top, see Figure 7.

For the GUI of the daily self-evaluation questionnaire, three questions with touch areas for answers were displayed with a legible text on a tablet device, see Figure 8. Outcomes from further iterations' sub-phases contributed to refine the user requirements and improve the application implementation.

Based on the initial GUI, a first prototype version was created. Figure 9 shows the first prototype version of the measurements' screen with the buttons "Measure Pulse" and "Send Pulse Value". The readings of SpO<sub>2</sub> and pulse are

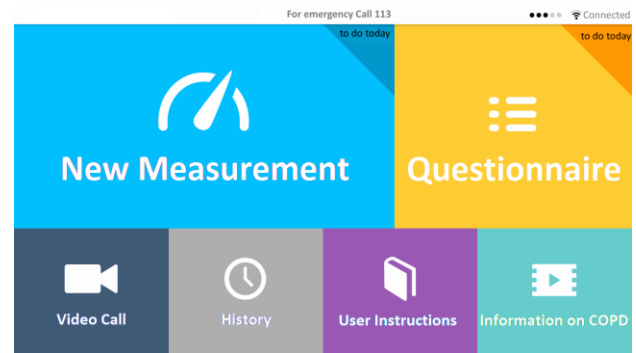


Figure 7. GUI of tablet application main screen.

shown in the right column (e.g., pulse = 85 beats per minute, and SpO<sub>2</sub> = 98%).

Figure 10 shows the initial prototype version of the questionnaire's UI, with one question per screen. The list of answers had to be touch-selected. A "Next" button to advance to the next question was placed under the list of answers.

2) *Functional Test:* In each iteration during the development of the application, a functionality test was run by the development team. The identification of errors at this stage proved to be relatively cost-effective to fix in terms of time and effort compared with further sub-phases.

3) *User Evaluation:* The user evaluations in laboratory settings comprised tasks to perform in the tablet application. An in-depth analysis of the observations revealed a number of usability issues. For the GUI, several problems were identified due to the insufficient text size in the UI of the measurement's screen and related to the progress bar. Some spelling errors were found in the UI wording. For the functionality, there were some technical issues related to transmission of data from the tablet device. The videoconference sound quality was insufficient, but the use of headset improved the communication. Further, while the 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 these issues.

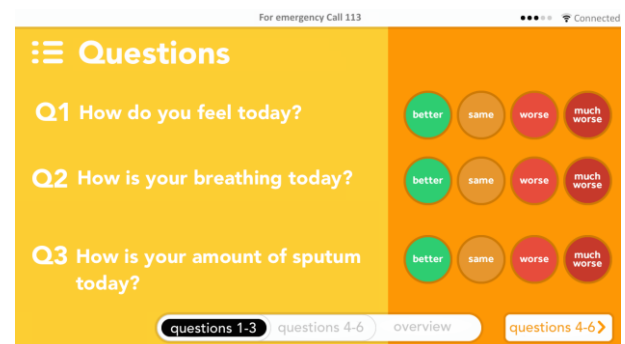


Figure 8. The GUI of the daily self-evaluation questionnaire

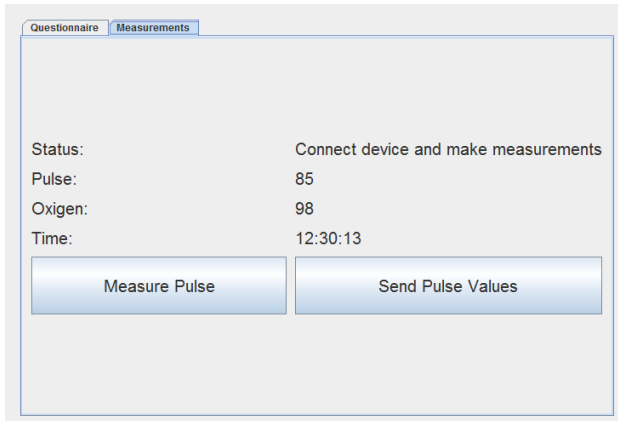


Figure 9. First prototype version of the measurement screen

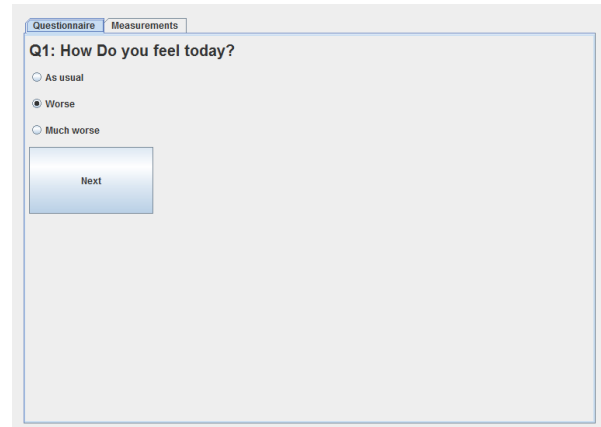


Figure 10. First prototype version of the questionnaire

In the group interviews after the evaluations, user comments about the tablet use were overall positive. They refer to the usability of the application and its functionalities: “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”. Comments also addressed the feeling of safety after using the system for few days in a row: “This is a fantastic procedure and a nice service for COPD patients. Initially I was skeptical because I was afraid this would be too technical and little human, but now I think this will give patients a feeling of safety, especially the first 14 days after hospital discharge”. Other 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 the videoconference with telemedicine centre. I think it is good to see and hear the nurse for users at home”. About the interaction with the tablet device, one of the patients stated: “I assume finger interaction will work well for most elderly people”.

The tablet application went through several iterative refinements to implement the findings from the user evaluations. These refinements included the display of the questionnaire with the adequate number of questions per screen, reduced from 3 in the initial GUI design to finally 1 per screen in the final implementation to ease the individual reading. A review of the questionnaire’s answers was included to allow patient to double check the filled-in answers before sending them in. Initially, a progress bar notified data transmission but it was unclear for distinguishing between successful and unsuccessful data delivery. A feedback notification pop-up window was shown, displaying a round face with an associated color code (i.e., green smiley face for successful delivery and red sad face for unsuccessful one). In addition, the user manual with intuitive images to guide step-by-step how to handle the measurement devices was requested. In this line, the GUI

corresponding to the new measurement was improved by reducing the information load to perform tasks.

4) *Field Trial*: The usability evaluations performed during the field comprised 4 tasks with associated sub-tasks and several usability problems were revealed. In the GUI of the measurements’ screen, the text “New Measurement” was used twice, as a heading but also as an action bar, creating confusion on which was one had to be selected to start the action. When choosing the action bar, a pop-up window opened over the instruction text, impeding its reading. The size of the touch area to answer the videoconference call was too small. Regarding the interface design, the text size was evaluated as sufficient and the choice of colors as appropriate. The interface of the main screen, measurement and the symptom self-evaluation questionnaire were easy to understand and had sufficient contrast between the elements. In the questionnaire, the size of boxes was sufficient and the overview of filled-in answers before sending was evaluated as a positive feature. For the application’s functionality, there was a lack of notification to the user when there was a data transmission error. For instance, a progress bar showed on the screen an ongoing transmission, but without notifying whether the transmission was successful or not. In addition, the videoconference had problems with sound and video quality. Initially, the quality was rated as satisfactory, but it presented some minor sound and video problems. Only one participant rated as satisfactory the videoconference quality during the whole test. The touch area to answer videoconference call was too small.

Regarding users’ interactions with the tablet device, the double touch action was problematic because users had to apply the correct touch speed and pressure. A stylus was required in some cases. One user had forgotten the correct action for starting the application and found a way around by touching another UI area. When adjusting the camera in the videoconference, one user accidentally switched off the application twice before succeeding.

The interviews showed that all participants successfully connected the equipment by themselves at home. The instruction manual was evaluated as clear and instructive, but

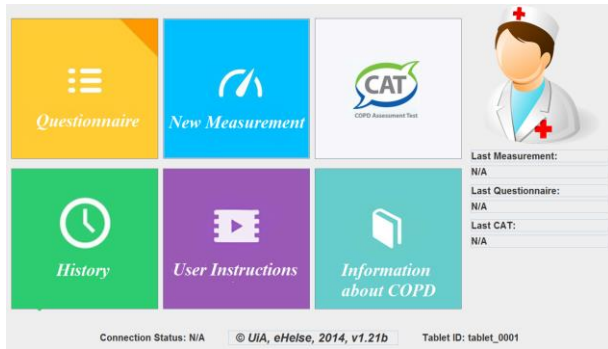


Figure 11. The final version of the UI's main screen

some mismatch between the content shown in the manual and the final text and layout shown in the system had to be resolved. The main frustration expressed by participants was the videoconference problem, which was related to mobile network coverage. For the interaction with the UI, most users stated that during one week they became familiar with the correct speed and pressure for touch actions.

Based on findings from the field trial, several refinements were made in the tablet application, such as the automatic start of the application because of problems with touch initiation of the program icon (i.e., 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 patient. The videoconference image and sound quality was improved through software configuration changes. The sound quality was improved by the selection of optimal headphones and microphone setup for the users.

The participants' overall rating of the application was satisfactory concerning all interactions with the tablet (e.g., equipment setup, device connection, measurements, questionnaire filling, data transmission, and

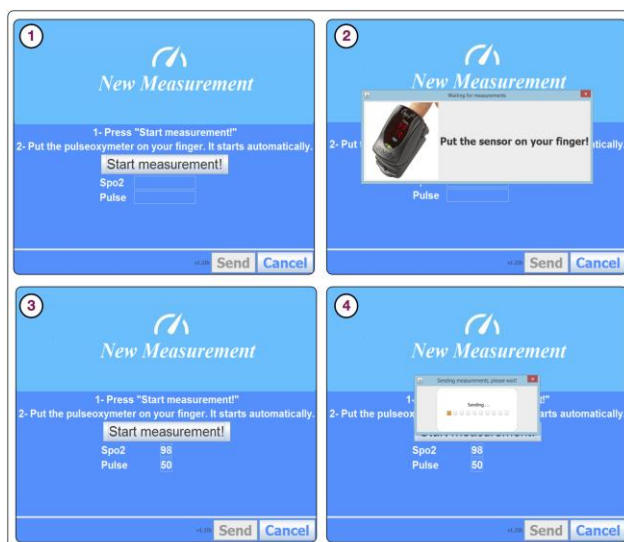


Figure 12. (1) The final version UI's of the New Measurement screen. (2) Pop-up window with instruction. (3) Readings of SpO<sub>2</sub> and pulse. (4) Progress bar.



Figure 13. Notification window for successful sending (left) and for unsuccessful sending (right).

videoconference). Comments referred to the design, understanding and usability of the system: "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 concluded the development of a final version of the tablet application, which was evaluated as "satisfactory" in all the sub-phases. Users started to operate the UI from the main screen of the application. The screen was divided into six differentiable touch areas with the daily functions at the top (e.g., "Questionnaire", "New Measurement" and "COPD Assessment Test". Figure 11 shows the final UI of the tablet application.

The series of steps related to the task of taking a new measurement is shown in Figure 12 and 13. The procedure included pressing the button "Start measurement" to start the operation (see Figure 12.1). When starting the measurement, a pop-up window opened and visually showed how to place the sensor on the finger (Figure 12.2). When successfully measured, the readings of SpO<sub>2</sub> and pulse were shown in the two fields and the button with the label "Send" would become active to send the readings to the telemedicine centre (see Figure 12.3). When pressing the "Send" button, a progress bar showed the text "Sending", representing the ongoing transmission of data (see Figure 12.4). When the data were transmitted, a feedback notification pop-up window opened to alternatively show successful or unsuccessful data delivery, see Figure 13.

The questionnaire for the daily self-evaluation of symptoms consisted of a sequence of 9 screens, 7 for the questions and 2 for reviewing and reset the answers when necessary. The question screen showed the possible answers to be touch-selected and a button with the text "Next" to continue with the remaining questions, see Figure 14 left.

The questionnaire review screen showed the answers selected and gave the possibility of resetting them when necessary. In addition, the button with the text "Send" would submit the answers to the telemedicine centre and the button labelled with "Cancel" would cancel the whole operation discarding the answers, see Figure 14 right.



Figure 14. The final version of the UI's daily self-evaluation questionnaire, question 1 (left, Q1) and answer review (right).

## V. DISCUSSION

This paper has presented the UCD process for the development of a tablet device application for remote monitoring of COPD patients in home environment. Telemedicine applications typically involve 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 of COPD patients, it has been confirmed by end-users (i.e., COPD patients and health professionals) that the employed UCD approach included their needs in the development of the application. The workshop with end-users efficiently outlined user needs, context of use and helped the user groups involved to familiarize themselves with each other and the research team. Therefore, the workshop was the key to elicit users' requirements of the application, taking on board different aspects of GUI, interaction and functionalities.

The user evaluations were carried out both in a controlled laboratory environment and at COPD patients' homes. The early evaluations in laboratory environment simulated a realistic user scenario based on constructed role-play scenario where the patients and health care professionals interacted with the technology. In addition, the laboratory provided a test environment allowing controlling the variables studied and enabled users to give feedback about GUI design and the interactions following the remote monitoring process. The laboratory test was a necessary step where to evaluate the iterations for the refinement of the application. Finally, the controlled test provided the necessary safety for, as seen in other studies, afterwards running the field trial in an optimal way [30].

The field trial allowed studying the long-term and real-time usage of the technology by COPD patients at their home and provided useful information about the interactions

between humans and technology, but also between the different technologies involved. This helped to address the common issues with interoperability [38], present nowadays in the deployment and use of telemedicine technologies [39][40].

Several lessons were learned during the study that can be transferable and applicable for technology development for other chronic clinical pathways (RQ2). In particular, intended solutions for medical environments necessarily need to firstly involve all the user groups in the creation of the solution. Secondly, the respective analysis of how this solution could best fit in an existing clinical workflow or, if non-existent, embedding the solution in a new workflow built up in collaboration with the end-user groups. Thirdly, the fact that chronic patients do not have the same levels of physical energy as healthy people underlines the importance of designing easy-to-use solutions that minimise physical effort and mental workload.

The research study of the UCD process had also some limitations such as: patient role-play by health professionals, user-scenarios tested in a simulated environment and reduced number of end-users. The health professionals took the role of the patient in the user evaluation 1 due to the low legibility of interface wording (as it can be seen in Figure 9 and 10). This was improved in the user evaluation 2, where real patients tested the interface. The simulated test environment allowed creating highly realistic scenarios under controlled conditions, and the field trial gave the opportunity to test the system in real-world settings. The number of users, despite low, meaningfully represented all the end-user groups involved [41][42].

## 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 the evaluation in the laboratory settings, regarding ease of use of the telemedicine solution and user satisfaction. The methodology employed, UCD, transformed the end-user into a contributor of the telemedicine service design and allowing continuous refinement of the application to fully develop the system suitable for remote monitoring of COPD patients.

The telemedicine service enabled COPD patients reporting their symptoms and health status after hospitalization. The system is interoperable with other concurrent systems, resolving the common issue of interoperability present in the deployment and use of telemedicine technologies. The continuous report of symptoms for chronic patients throughout the whole health service chain together with actively including patients 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" [43]. This EU strategy aims to help current health care systems placing the patient at the centre of new treatments for chronic conditions included in the projections of global mortality for 2030 [8], such as ischemic heart disease and diabetes.

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 whether deployment is successful, but the efficient and continuous use of technological solutions.

Finally, the proposed UCD process has been validated by the development of a telemedicine tablet application, successfully adopted by the EU FP7 project United4Health, which focused on technologies that support remote monitoring of COPD patients after hospital discharge. As a result, 3 telemedicine centers covering 23 municipalities in Norway are currently using the final version of the application. This represents a significant contribution compared with related scientific literature where many telemedicine studies do not reach final deployment stage.

Future work will 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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