A Pervasive Solution for Validating Oximetry Measurements And Physical Training Guidance in Unsupervised Settings

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Abstract—An alarming 4-10% of the world's population suffer from Chronic Obstructive Pulmonary Disease (COPD). The aim of the present project is to improve life quality and provide assistance in needed physical exercise in a safe way, ensuring peace of mind for patients.

Using the ASEF framework's methodical approach, a healthcare device prototype has been developed. The user interface is designed and tested for the specific target group, with focus on providing valid measurements of pulse oximetry in unsupervised setting. Furthermore a simple interface contributes to the needed reassurance during physical exercises.

The solution can help provide higher quality of life for patients, while simultaneously be a useful tool for the healthcare professionals. Overall the device is not only easy-to-use but could also ease some of the economic pressure on the public health care sector.

Keywords: COPD, unsupervised measurements, physical training guidance, reassuring patients

I. INTRODUCTION

Worldwide 4-10 % of the population suffer from Chronic Obstructive Pulmonary Disease (COPD) [1], while danish numbers are estimated to be around 8 %[2].

Every patient with some sort of disease has an specialized Adherence Strategy, which can consist of different Adherence verifiers and aids[3]. The aim of this project is to develop a pervasive solution to help patients suffering from a late phase COPD. The pervasive solution should be an Adherence aid, to guide the patient to a higher level of self care.

Many patients suffering from COPD experience ups and downs - which in some cases end up with a hospital stay. A study from United Kingdom indicate that these hospitalizations in some situations can be prevented with a simple pulse oximetry measurement. The study has examined the use of pulse oximeters in primary care. It showed, that the use of pulse oximeters reassured patients in 61 % and the general practitioner in 67 % of the cases, meanwhile the system was easy to use[4].

A way of keeping track of the COPD patient's state of health is by following the oxygen saturation continuously. A continuous string of measurements have to be made under unsupervised settings, this poses a potential problem with the validity of the measurements. To secure the validity of the measurements, certain conditions have to be fulfilled. The users are aided for a better adherence and hence a better measurement.

The first part of the present study's hypothesis is, that it is possible to design a pervasive solution for elderly patients with COPD in late phase, with the aim to secure a higher level of validity of the oximetry measurements taken in an unsupervised setting by using different contextual sensors.

In addition to the part concerning valid home measurements, another part was added to the pervasive solution. This part works with physical activity, because it is the best non-pharmacological treatment. The second part of the hypothesis was that distinct visualization of the oxygen saturation during physical activity would help and reassure the patient during exercise.

II. METHODS AND MATERIALS

Following the ASEF[3] a RAM was designed with focus on skin temperature and patient movement (figure 1).

The evaluation prototype consists of a user interface shown on an iPad and three different sensor types. The main sensor is the Nonin Pulse Oximeter[5] with built in Bluetooth connection, for measuring the oxygen saturation in the blood. The second sensor type is a three-axis Phidgets accelerometer [6] for detecting any patient movement. Thirdly the skin temperature is measured with a Phidgets Precision Temperature Sensor[7]. The Phidgets sensor was used because of the simple implementation through an USB port. (see figure 2)

The iPad user interface is a software application executed on a laptop through the app *AirDisplay*[8]. The application uses the iPad as a second screen with touch technology instead of a cursor. The graphical part of the evaluation prototype is drawn on the iPad and imported to the software afterwards.

Full Adherence Model

- Intense surrounding light
- ***Severe movement***
- Electronically interference
- Using other technology equipment (for example sphygmomanometer)
- Moisture in the sensor
- Incorrect installation of the sensor
- Incorrect sensor type
- Undetectable pulse
- Vein pulsation
- Anemia or low hemoglobin concentration
- Nail varnish
- ***Cold fingers***
- Smoking before measurement
- The sensor is not placed in the same height as the heart

Figure 1: FAM with RAM highlighted [9]

The user interface is divided into two different parts (figure 3). The first part is developed to make valid oximetry measurements in the unsupervised settings. This part uses all three sensors and the data from these to find the validity of the data. The oximetry and validity data are then send into a cloud function enabling the general practitioner to evaluate the patient's health. The second part of the user interface is an intuitive guide for unsupervised physical exercise. In this part the accelerometer is switched off because physical exercise without movement is difficult. Furthermore, the validity of the measurements is less important during physical exercise since the aim is to reassure the patient.

Figure 2: Sketch of the prototype

The graphical user interface is heuristic evaluated using Heuristic Evaluation[10, 11] which is done by an expert group consisting of five members. This test is chosen to secure a simple and easy-to-use interface. This is important in any product, but especially in this case because of the market segment.

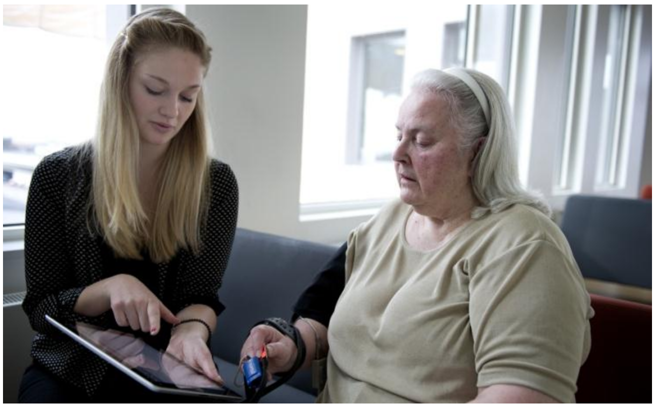
Afterwards a pilot test[12] was made with three random users with no exhaustive knowledge about the project and its aim. This trial was completed to test the technical operation with focus on inappropriate errors under practical circumstances before the main test.

Figure 3: Flowchart with screenshots from the prototype

After the pilot test a Think-aloud protocol was conducted with four participants. The participants were prescreened to secure the representativeness by asking about their age gender and IT literacy. If found representative the participant was given a typical description of a COPD scenario with build-in practical workout with the evaluation prototype. The participant was asked to talk out loud with any thoughts on the prototype while handling the system and these statements were noted by two observers.

III. Results

The evaluation of the prototype was completed in three steps. Firstly the Heuristic evaluation was done. It was found, that the prototype generally seen meets the heuristics[10, 11]. Point number five (Error prevention) and point number nine (Help users recognize, diagnose, and recover from errors) were not found relevant under these circumstances, but would be an important part of the finished product.



Picture 1 Think-aloud test of the user interface (Photographer: Henrik Olsen)

The second part of the evaluation was the pilot study[12]. The aim of the pilot study was to test the Adherence verifier for technical errors. None of the four people in the test works professionally with IT, and their IT literacy is estimated to be average, and representative for the target group.

PRESCREENING		
AGE	47-69 years	
GENDER	2 women	2 men

Table 1 The result from the prescreening

The last part of the evaluation was the Think-aloud protocol[12]. The results from the prescreening are shown in Table 1. When the participants were asked to express their opinion about what they experienced, they primarily said positive things. For instance "*The functions of the system are easy to use*". Others said "*The illustrations are very descriptive*". A few of the participants commented on the issues about the slow responsiveness of the system, and about the size of the buttons and text, which was difficult to read.

To test the accelerometer in the prototype a group of 10 people, and 1200 samples in a total of 30 one-minute tests were used. The 10 people were acting out three different scenarios:

- Motionless, where the test-person would sit as motionless as possible.
- Normal, where the test-person would sit calm, but not unnaturally quiet.
- Motion, where the test-person would move around, shifting sitting posture several times.

Age and gender of the group is shown in table 2 whereas table 3 contains the histogram data from the collection. A bin size of 500 is used.

SENSOR TEST – TEST-GROUP DATA		
AGE	33-41 years	
GENDER	6 women	4 men

Table 2 Details on the participants in the sensor test.

BIN	MOTIONLESS	NORMAL	MOTION
500	7547	7687	6519
1000	3852	3544	3080
1500	578	769	1302
2000	15	0	526
2500	4	0	284
3000	3	0	158
3500	1	0	131
4000	0	0	0

Table 3 Histogram data from the sensor test.

Figure 4 is the graphical representation of histogram data from table 3.

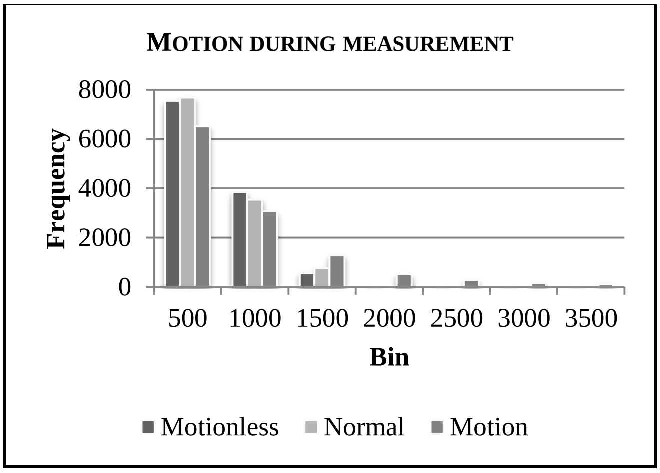


Figure 4: Sensor data histogram – full range

In all three scenarios an extensive amount of micro movements were detected. Figure 5 details measurements with vector lengths exceeding 2000 units.

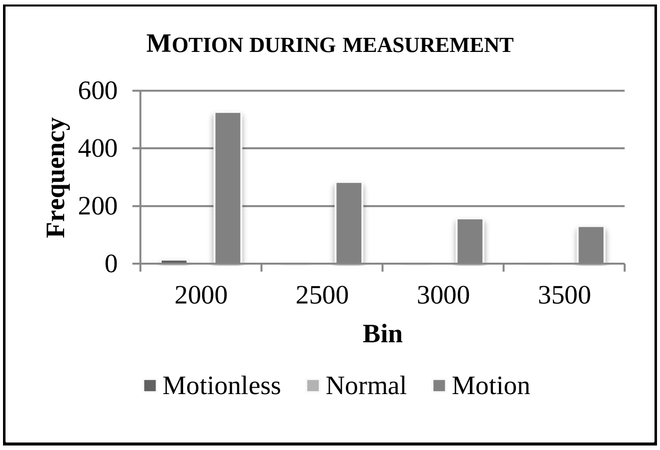


Figure 5: Sensor data histogram – high end

Furthermore was the head nurse Anne Toft at the clinic of respiratory medicine at Aarhus University Hospital, Aarhus Hospital, Nørrebrogade introduced to the system and liked the idea. Afterwards she stated that numerous patients affiliated to the clinic bought pulse oximeters themselves to be able to take reassuring measurements when feeling shortness of breath.

IV. DISCUSSION

In the suggested solution the sensors should be combined in a smarter way that enables the users to handle the system without any technical support. Concerning the software an algorithm calculating a validity standard of the measurement should be developed. The system should also be able to gather the measured information, pair it with the validity standard and send it into the cloud. This communication with the cloud service should be done in an international standard for health information to secure the usefulness of the information and the system in the future. Besides sending the information into the cloud, a local database should contain recent measurement, for later comparison to each other. Last but not least the presentation of the measured data in both parts of the application should be a graph - the part for physical activity should even be on runtime.

The aim of this project was to design a pervasive solution to help patients suffering from a late phase COPD. The pervasive solution should be an Adherence aid, to guide the patient to a higher level of self-care. This aim has been fulfilled with the development of an evaluation prototype enabling the patient to make valid pulse oximetry measurements in unsupervised settings and distinct visualization of the oxygen saturation during physical activity or when feeling respiratory distress.

The first part of the hypothesis of this study was to test the user interface in proportion to the market segment. Firstly the user interface was heuristic evaluated. Point number two (Match between system and the real world) was especially interesting, because the use of a proper language and design related to the market segment were an important part of the process of development. After the heuristic evaluation a think-aloud test was completed. This indicates that the idea behind the system and the design of the user interface were chosen correctly. Further studies on a refined prototype should be done on patients suffering from COPD to improve the quality of the results.

Data collected in the sensor-test (table 3), shows a significant drop in occurrences of motion vectors exceeding 1500, suggesting this level as appropriate for prompting the user with an textual Adherence aid, asking him or her to sit more quietly.

Using a t-test, it cannot be shown that there is a difference in the mean for people in the sensor test sitting still and normal (P is above 0,8). The same test does show that there is a significant difference in the mean between normal and motion ($P < 0{,}001$).

It could be argued that several motion vectors above 1500 units should be detected with a timespan of e.g. 10 seconds, ensuring a greater likelihood that the reading is actual movement. However this approach results in a more sluggish response. An option to cope with this dilemma could be to have several levels of prompting the user. Levels not based on the size of the motion vector, but on the consistency of occurrences of vectors exceeding the 1500 units boundary over a short time span.

The second part of the hypothesis dealt with distinct visualization of the oxygen saturation during physical activity. It has not been possible to confirm or disconfirm this part of the hypothesis due to lack of time and test extent. Though this part of the prototype has been tested in connection with the Think-aloud procedure when feeling respiratory distress. Testing it during physical activity would be an interesting and important test to proceed with.

The most important question to be asked is whether the pulse oximetry measurements are valid because of a temperature sensor and accelerometer. As listed in figure 1 a wide range of contextual bias can affect the validity of a pulse oximetry measurement. Furthermore the chosen RAM solution is still relevant because it features the pulse oximetry measurement with contextual sensors and the possibility to make a validation standard to the measurement.

Another important question is whether an iPad is the right user interface medium dealing with elderly as market segment. The participants in the think-aloud protocol were all representatives of the elderly with a lower level of IT literacy. All of the participants indicated that using the iPad would not give them any or only light problems and by that it is reasonable to draw the conclusion that using an iPad as medium for the user interface is a genuine possibility.

The temperature sensor is not an important part of this present evaluation prototype. Though it is a contextual bias (figure 1) if the temperature at the fingertip is too low and some material indicates that smoking lowers the skin temperature at the fingertip nearly momentarily[13]. An interesting potentiality of the temperature sensor that could be evaluated in another study could be to use it to detect smoking during a pulse oximetry measurement.

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