Smart Weight Monitor

Automatic home monitoring of normal and dry weight in diseased patients with validation of identification

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Abstract — **This paper proposes a novel technique for reliable monitoring of rapid changes in patient body weight over time, by using a prototype scale system. The changes in body weight are a result of fluid accumulation in the body that occurs in patients suffering from heart failure. Existing systems relies on self-monitoring where the patient is responsible for documenting and communicating forth changes in body weight. Using the Adherence Strategy Engineering Framework (ASEF) we designed a reduced adherence model (RAM). The proposed prototype is called Smart Weight Monitor, designed to increase patient adherence, be non-visible, perform reliable and automatic data-collection with internet-based data access and decrease patient responsibility for usage in a home-environment. Results of testing show that Smart Weight Monitor proved to be fully functional according to initial design and only collects weight data when verifying specific faces. However adherence of the protocol is dependent on key elements such as gender, size of toilet/room and individual toilet routines of the user, which adds to some contextual bias with the current prototype of Smart Weight Monitor.**

Keywords-component, weight-scale, heart failure, adherence pervasive healthcare, Smart Weight Monitor

I. INTRODUCTION

The importance of reliable body weight monitoring plays an important role in many different disease domains. This paper primarily focuses on heart failure. Using the Adherence Strategy Engineering Framework (ASEF) [1] a reduced adherence model (RAM) for reliable weight measuring has been developed. The RAM consists of a protocol for reliable weight measuring and is intended for use in automatic monitoring of development in patient body weight over time.

Heart failure is a condition where the heart is unable to pump a sufficient amount of blood through the body. With different types of heart failure the condition is classified by which side of the heart that is affected and causes the limited pumping ability. This reduction in the hearts' ability to circulate blood through the body causes fluid accumulations in the body leading to pulmonary and peripheral edemas, tiredness and shortness of breath. Heart failure is not an exact diagnosis and is therefore used as a general term because it may develop from various conditions such as: ischemic heart disease, myocardial infarction, diseases of the heart muscles/valves, hypertension and is in some cases caused by drugs, chemicals and some types of chemotherapy that may damage the heart muscle tissue [2].

The incidence rate of chronic heart failure in Denmark is 1/1.000 for men below 65 years of age and 0.4/1.000 in women. The rate is 11/1.000 in men above 65 years of age annually and 5/1.000 in women [3]. It is estimated that 1-2% of the Danish population is suffering from chronic heart failure. Furthermore, the risk increases with age. Another important aspect that should be taken into consideration is hospital admissions. The occurrence of hospital admissions in Denmark caused by heart failure is close to 11.000 a year, and makes up for about 5% of all admissions to the medical sector. The rate of admission has doubled over the last 15 years [3].

It is very common for people suffering from heart failure to experience rapid changes in body weight. The main cause of the sudden rise in body weight is due to fluid accumulation in the legs and ankles when the heart is affected on the right side. Similarly, fluid is accumulated in the lungs when the left side is affected. It is important for people suffering from heart failure to weigh themselves every day, at the same time of the day and notify a healthcare professional if a rapid change in body weight occurs. According to studies [4], evidence suggests that people suffering from heart failure gain a sudden and rapid change in body weight approximately 1 week before hospitalization occurs. If the gain in body weight increases by more than 2 kg in 3 days and up to 3 kg over a week hospitalization might follow. By monitoring changes in body weight on a daily basis it becomes possible to intervene in time so hospital admission might be avoided.

Current praxis and state-of-the-art is a self-monitoring system where the responsibility of both documenting and communicating changes in body weight is imposed on the patient. The current model is thereby reliant on the patient itself to perform valid measurements and keeping track of the self-monitoring process [9]. By analyzing the context of patient-routines in a home-setting environment it was concluded that a bathroom has good base for automated weight monitoring overcomes uncertainties from state-of-the-art and maximize patient adherence. The result is smart weight monitor, a well-designed ubiquitous scale system, which takes advantage of a routine most people perform every day. The smart weight monitor-protocol is designed to ensure routine to perform reliable body weight measurements upon identification verification followed by automatic data storage.

Key elements to the Smart Weight Monitor are that it is intended be non-visible, it requires no calibration before usage, it automatically only verifies identification on the person whose weight is needed, it receives dry-weight by capturing weight-data before and after a toilet visit and every weight measurement is logged with time and date in a database. By such the protocol of Smart Weight Monitor opens up the door for an aid in which patients have no responsibility but performing the protocol and healthcare professional would be able to access each patient's data at any time from a any computer-device via internet.

The aim of this paper is primarily to evaluate the prototype scale according to the SWM-protocol and document the results as proof-of-concept.

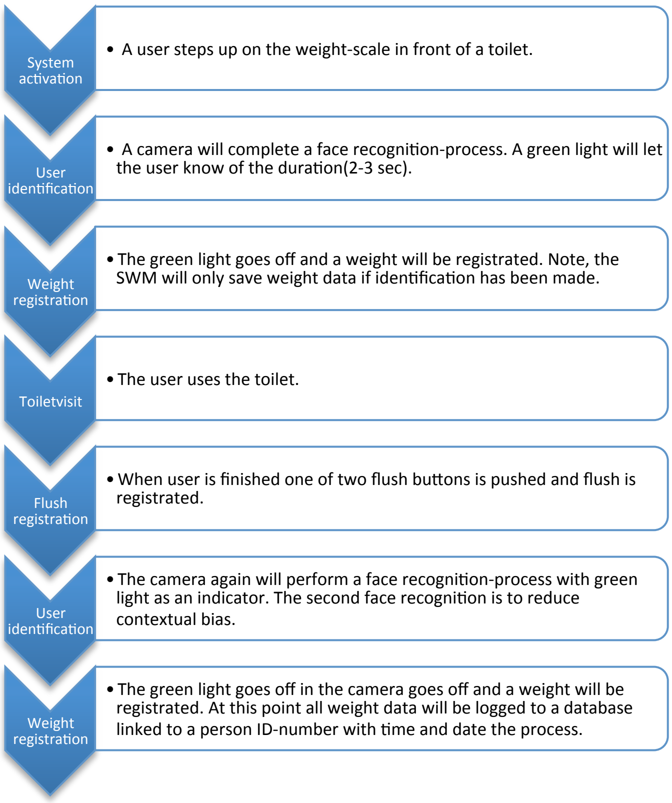

Figure 1, Smart Weight Monitor-protocol.

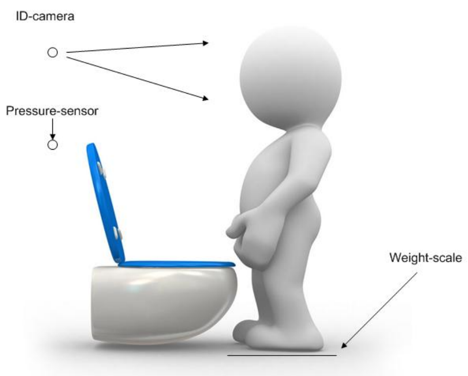

Figure 2, Smart Weight Monitor showed in a contextual environment.

II. SUGGESTED SOLUTION

First part of suggested solution is a Smart Weight Monitor with further improved weight scale, face recognition, a complete non-visible design and a designed architecture for the aid. The weight scale would need two improvements. It is important that the weight accuracy is very high as weight data is interpreted by doctors, nurses etc. Therefore it would be needed to have weight scale, which is medically certified. Furthermore a new design of the weight scale would be needed so that the weight is non-visible and embraces a larger surface. This means that we would like to build a new accurate weight that is only as thick as a bathmat, which would be aiming at height of approximately 1 centimeter.

The camera also needs to strive towards being non-visible on the wall wireless or with hidden wire. Face recognition software must be improved so that it encounters light, distance and facial changes. With all improvements above a suggested solution for Smart Weight Monitor embrace that fact the system appears non-visible and performs with reliable data-measurements and face recognition. The suggested solution for the Smart Weight Monitor would require nothing of the patient but to follow the protocol. The aim is that the patient experience minimal changes with no heavy burden of responsibility fully relying on the Smart Weight Monitor as an adherence verifier.

Second part of our suggested solution is the aid. The Smart Weight Monitor can be used in several domains, which means the suggested solution for the aid will differ depending on domain. Our choice of domain is heart failure. The Smart Weight Monitor data should enter a web server-database instead of a local database. This would open up accessibility for any healthcare professional to access patients' data with ID-number and follow development or view data-historic with a PC, tablet or a smartphone. Furthermore the Smart Weight Monitor allow for access to both normal and dry weight of patient using the system.

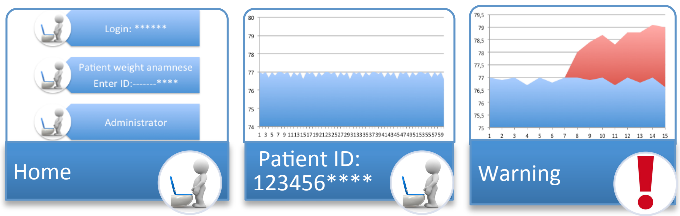

Figure 3, Illustration of suggested aid application for Smart Weight Monitor.

Another function that can be built is an alarm-function. By using an adjusted weight-threshold the Smart Weight Monitor can monitor weight anamneses of patients with heart failure and send out an alarm when the weight surpasses a threshold. The alarm could be send to a specific and relevant health department. This might increase treatment possibilities for healthcare professionals. Administration of medicine can be adjusted more efficient which it might increase life quality for patients [7].

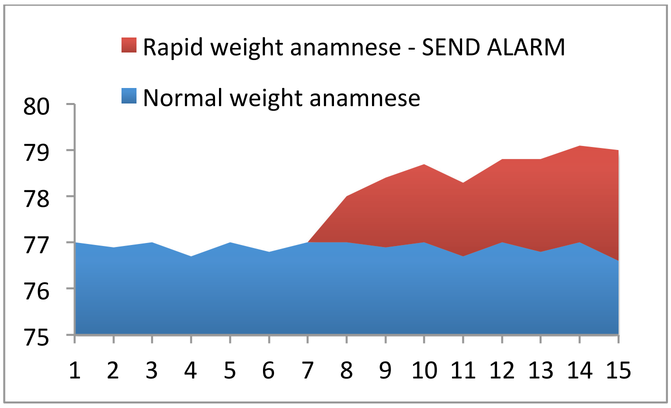

Figure 4, Illustration of the concept of an alarm aid with Smart Weight Monitor for patients' with heart failure.

III. METHODS AND MATERIALS.

A. *Methods*

We followed the ASEF method [1] for analysis, design and evaluation of the SWM system. In an iterative process we developed an evaluation prototype for testing the system. The SWM-protocol was evaluated by proof-of-concept and to accomplish this, the following three methods were used:

1. Heuristic evaluation
2. Pilot test
3. Think aloud test

It is important to stress that through all of these tests participants only imitated their normal toilet routine of urinating as we tested proof-of-concept. We performed our tests in two different bathrooms. One of the bathrooms was small room and the other was a larger handicap bathroom. The authors acted as observant and technician. The observant assisted in writing down data for each of the tests and a technician helped reading in pictures of the participants' faces before the tests could begin. The more pictures in the database for one person the greater the accuracy of the face recognition process. Both an application and a database where made to assist in this process.

Heuristic Evaluation

A heuristic evaluation was made by the authors to test the usability of Smart Weight Monitor-protocol [10]. All men were instructed to imitate their toilet routine. The focus of the heuristic evaluation was on following subjects:

- Weight scale usability
- Camera usability
- Toilet-flush usability

Pilot Test

A pilot test was made by the authors to validate the Smart Weight Monitor unknown to the system, but introduced to the SWM-protocol. Subjects were all men instructed to imitate their toilet routine. Test subjects were screened for the pilot test, according to their level of IT literacy, to determine their opinion towards SWM. All test subjects tested the SWM-protocol individually, and their actions and commentaries were noted by the observant, so early state errors of both technology and protocol could be corrected.

Think Aloud Test

This test was made by the authors to gather data about the usability of the design of the prototype and the SWM-protocol. Both men and women were subjected to imitate their toilet routine. The test subjects were instructed to describe their actions and think aloud as they were completing the SWM-protocol. This test made it possible for the observant to observe, note and listen to the subjects using SWM. Furthermore, we wrote in our application a function, so that weight, time and date and time of face recognition process showed after each test.

B. *Materials*

The technology used to evaluate the SWM-protocol consisted of sensors, both on the toilet (Flexiforce) and in the custom-made weight scale (FC22). A web camera was used for identification of the patient and a database to collect the weight data.

Four weight sensors were used to create the prototype weight scale made up by two plates with the sensors in between. Two pressure sensors that register when the patient flushes after being to the toilet. For face recognition of the person on the scale, one web camera was used, and one SBC to connect all sensors. To the SBC a router was connected, creating an access point for the system, making it able to transfer data to a computer that is requesting the information.

Software:
Verilook Standard SDK from Neurotechnology
Sensors:
2 x Pressure sensors, FlexiForce, Tekscan
1 x Webcam (Direct Show Compatible USB)
Weight scale:
Custom made sheet metal
4 x Weight sensor, FC22, measurement specialties. Ltd
Computers:
1 x Laptop (Windows7)
1 x Single Board Computer (Phidgets SBC)

IV. RESULTS

All the results that have been obtained through the tests listed in methods and the results are qualitative.

A. *Heuristic Evaluation*

- The weight usability was tested with full functionality receiving a weight before and after toilet visit.
- The camera usability was tested and proved that identification can be made of the user in both the first case and the second case.
- The toilet-flush usability was tested with full functionality working with no errors.

The SMW proved to be fully functional by correctly providing weight-data according to design of SWM/SWM-protocol. Note this evaluation does not consider inaccuracy in weight-data and that the gender of persons that where tested where men.

B. *Pilot Test*

The test subjects consisted of five men, and they all noted that they had a high level of IT literacy. Weight and camera usability worked correctly with the male test subjects. The subject found the plate of the scale unstable and was a little insecure stepping up on it. The data collection on 5 participants showed that the average weight deviation between first and second weight registration was 200g. The average time of face recognition was 1.91 sec and 1.93 sec for respectively 1. and 2. face recognition.

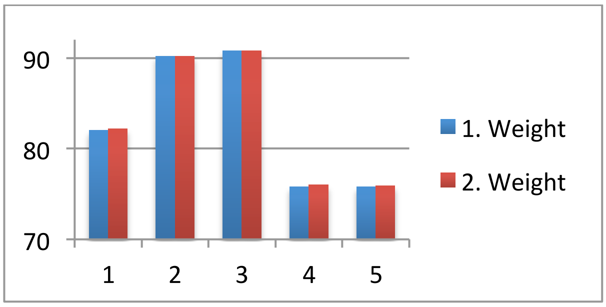

Figure 5, Diagram shows weight (X-axis) data in interval of 70-95kg from pilot test.

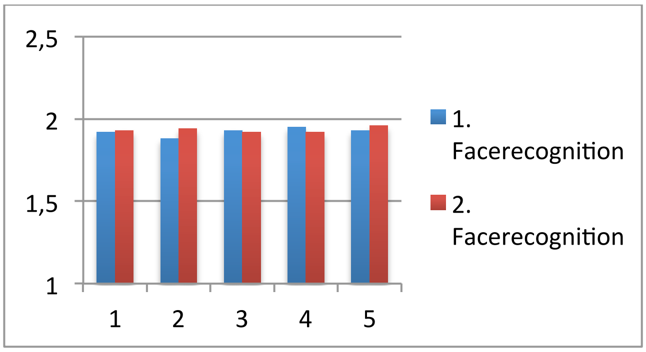

Figure 6, Diagram shows in seconds (X-axis) the duration of face recognition during pilot test. All participants of the pilot test were men.

C. Think Aloud Test

The think aloud test was made with 11 individuals with average age of thirty-two. This is well below the average of patients with heart failure. For men the test showed that when imitating their bathroom routine no problems was experienced when using SWM. But two test subjects mentioned that they would like to have an indicator for successful completion of the process of face recognition and weight-data collection. For women the test identified that a problem with the last face recognition might occur. The problem basically is that if the user flushes before zipping up pans the timing of second face recognition will not be good enough. The consequence of the second face recognition not being performed is that the SWM does not send the second weight measurement to the database.

V. DISCUSSION

In this project we have aimed to design a reduced adherence model by using key elements from the Adherence Strategy Engineering Framework. The aim of the paper has been to both test and evaluate Smart Weight Monitor and to document results as proof-of-concept.

The usability of the Smart Weight Monitor has proved to be fully functional as proof-of-concept according to the initial design. However in tests we have found contextual bias in the second data-collection of both ID and weight, which showed to be dependent on gender and distance from the camera. The reason why we measured time of face recognition is that if the process is too slow, it will cause contextual bias in the SWM-protocol and eliminate the initial design of automatic weight monitoring. As showed in figure 5, face recognition time proved to be consistent and fast. Men's bathroom routine had no usability issues as they were standing in front the camera at all time and therefore did not lead to contextual bias. Women's bathroom routine had contextual bias because they have to stand up afterwards. Non-the less we have proofed that the concept of SWM works in a contextual environment with healthy participants.

Early tests showed that distance could increase the duration of face recognition process with the current algorithm. This adds to contextual bias because SWM does not save weight data of a user whose identification is not verified. An important point made by a female participant in the think-aloud test was, that if she flushed and were not standing up facing the camera, she would not get identified the second time and she would not know that she missed the identification process. She and two other participants commented that after flushing an indicator would help inform the user that they had been identified properly.

It is important to have a weight-scale with a high accuracy to differentiate normal- and dry weight. This is to ensure that small changes in body weight are registered before and after flushing. The weight-scale in this project was a prototype, which needs further development regarding accuracy of the scale. The precision of the current weight-scale is 0.5+- kg. The weight results showed in figure 5 cannot be perpetuated as continuity because we need a higher number of measurements per subject.

A pressing issue regarding the current design of the SWM is the implementation of a camera inside the bathroom. Having a video recording device inside the bathroom can be viewed as an invasion of privacy and it may lead to a refusal to use the system by the users. One of the solutions of this issue could be voice identification.

Another domain we have looked into has been chronic kidney disease. With prevalence of 3-400.000 in Denmark it proves be a relevant health issue [6]. An assessment of the nutrition status of nephrology patients is essential because they as patients are especially at risk of malnutrition. The assessment, which is used, is called Subjective Global Assessment and has its focus on albumin, BMI and weight anamneses [5]. It is especially parameters such as BMI and weight anamneses that fit well in both the aid and protocol like the one of Smart Weight Monitor that aims to collect dry weight, weight anamneses and patient identification.

The SWM could be considered in health related issues like obesity and diabetes. Also institutions that are conducting trials with test a person, who in that process needs to be weighed with both high accuracy and adherence [7].

VI. ACKNOWLEDGMENT

Aarhus School of Engineering: Rasmus Elm Sørensen, carving out sheet metal for weight scale.

VII. REFERENCES

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