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ESUMS: A Mobile System for Continuous Home Monitoring of Rehabilitation Patients*

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Abstract— **The pressure on the healthcare services is building up for several reasons. The ageing population trend, the increase in life-style related disease prevalence, as well as the increased treatment capabilities with associated general expectation all add pressure. The use of ambient healthcare technologies can alleviate the situation by enabling time and cost-efficient monitoring and follow-up of patients discharged from hospital care. We report on an ambulatory system developed for monitoring of physical rehabilitation patients. The system consists of a wearable multisensor monitoring device; a mobile phone with client application aggregating the data collected; a service-oriented-architecture based server solution; and a PC application facilitating patient follow-up by their health professional carers. The system has been tested and verified for accuracy in controlled environment trials on healthy volunteers, and also been usability tested by 5 congestive heart failure patients and their nurses. This investigation indicated that patients were able to use the system, and that nurses got an improved basis for patient follow-up.**

I. Introduction

Hospital beds are expensive. Patients are therefore increasingly discharged from hospital at an early stage when the condition make it possible, and the patients are being followed up by means of visiting nurses or various degrees of home monitoring [1, 2]. The possibility to stay at home while being cared for is also often by patients perceived as more attractive than the hospital bed.

Remote monitoring systems, where measurements of patients' vital signs are taken in the patient's home and transmitted to care professionals have potentially great value for improving the follow-up of patients, provided that the system is set up correctly [3, 4]. These systems can facilitate daily follow-up of selected patient parameters; for the case of congestive heart failure (CHF) patients, weight, pulse and blood pressure are commonly captured on a daily basis.

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Many rehabilitation and chronic disease patients need to "hardwire new ways of conduct" by making life style changes or other adaptations to manage their chronic disease condition [5]. For this, they need to establish self-care base lines from which to define life style targets, and they need day-to-day feedback from health professionals on their progress. Daily point measuring systems are inadequate in this setting as they are unable to report on what the patient actually does during the day. From the patient perspective, there is also a need to learn more about own physiology and disease, thus empowering the patient to take charge of own condition. It is however crucial both for the patient and the health professionals that the systems are designed to meet end user needs and match actual care flows.

The use of wearable sensor devices can be helpful in home rehabilitation, and several approaches have been developed, see for example [6] and references therein. Wearable systems are attractive as they make it possible to carry out continuous measurements. Whereas many wearable monitoring systems aim for long-term 24-7 patient monitoring, wide uptake of these approaches are challenged by difficult battery charging, device obtrusiveness during daily activities and other usage or patient acceptance issues. However, as long as the planned usage is time-limited, for example during some weeks to establish of new life style base lines, it is easier for patients to accept being monitored. Wearable systems incorporating ECG or heart rate monitoring, as well as various patient activity monitoring capabilities, have been developed using both body worn devices [7, 8], as well as approaches integrating sensing functionalities in fabrics, see e.g. [9].

Commercially available home monitoring systems are usually proprietary, and offered from a single vendor. This vendor lock-in makes it more difficult for health care providers to freely select and optimize their system. Therefore, a modular, open system with exchangeable components, allowing integration of components from competing health informatics and sensor providers, offers a path towards lower operation costs, and also allows easier configuration of sensor functionality for individual patients.

We report on the development of an integrated system initially developed for home monitoring of congestive heart failure patients that has been discharged from hospital. The Enhanced Sustained Use Monitoring System (ESUMS) consists of the following main components:

1. *Wearable Vital Signs and Activity Monitoring Device (Wearable Device)*, which is attached to the chest of

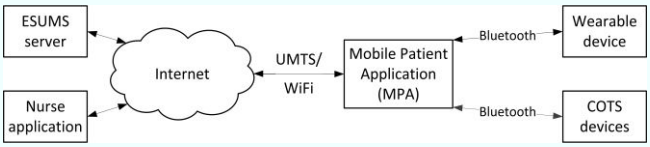

Figure 1. ESUMS architecture

the user, measuring heart rate, activity, posture and skin temperature on a continuous basis, and transmitting measurements by means of wireless Bluetooth communication.

2. *Mobile Patient Application (MPA),* which runs on a patient touch screen smart phone, integrates measurements from patient measurements, and forwards it to the corresponding server solution. The MPA also supports integration of other (3rd-party "commercial-off-the-shelf" (COTS)) vital signs monitoring devices.
3. *Server Solution* for aggregating and accessing data. This is designed employing a service oriented architecture and open source code.
4. *Nurse application*; a PC Java application allowing health personnel to integrate remote monitoring into their work flow.

Following the spirit of ambient health care, the ESUMS system has adopted the comprehensive health monitoring services approach where patients are offered the possibilities of continuous monitoring regardless of time and location. The ESUMS system offers improved decision support to the specialist nurse through access to continuous cardiac and activity data, thereby helping him/her to guide the patient to change habits and establish new baselines for daily activities. Through access to own data, the patient is given improved understanding and motivational feedback. As the system is based on open standards and service oriented architecture, it also allows integration of sensor devices from other vendors.

II. System Description

A. ESUMS System Architecture

The ESUMS architecture depicted in Fig. 1 consists of sensors (the ESUMS *Wearable Device* and any additional COTS devices), a mobile phone with the Mobile Patient Application (MPA) to relay data from the sensors to the server, a *Server* to receive and store the data and the *Nurse Application* that displays the data to the caregiver. Both the *Wearable device* and the MPA are designed to record health parameters over time and buffer them until they can be uploaded to the *Server*. This buffering solution enables the patient to use the *Wearable device* to record data without having to stay within range of the mobile phone. Likewise, in periods without network access to the *Server*, the data will be stored locally, and will wait to be uploaded once the *Server* connection is reestablished.

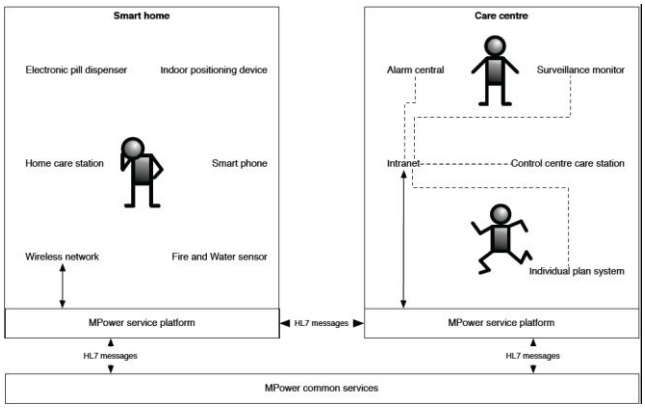

Figure 2. The MPOWER Architecture**.**

The ESUMS server solution represents an extension of the MPOWER platform, which was developed in a European Commission funded research project (IST-034707) [10]. The MPOWER architecture is shown in Fig. 2. The MPOWER platform is designed to support home care scenarios where there is a geographical separation between the patients (subject of care) and caregivers. The MPOWER platform is an open source service oriented architecture based middleware that allows for rapid development and deployment of services within a context of ambient assisted living [11]. This approach was chosen to reduce the work effort needed to develop the required ESUMS services. The *Nurse Application* is designed as an end-user application and will download patient data associated with the nurse that logs onto the application. The *Nurse Application* fetches all new data from the *Server*, and identifying patients that have sensor-values that are outside acceptable range.

B. ESUMS Prototype

1. Wearable Vital Signs and Activity Monitoring Device

The sensor electronics of the *Wearable device* is placed in a plastic housing. The electronics housing is attached to an electrode belt that is strapped around the chest of the user using snap buttons, see Fig. 3. The chest belt contains


Figure 3. The ESUMS *Wearable device* (in front) with mobile phone running the *Patient Application* (behind).

Figure 4. Illustration of the "View own data window" of the Patient Application.

elastomer electrodes for one-lead ECG. The device is battery driven and measures heart rate extracted from the ECG measurements, activity levels and posture extracted from a 3-axis accelerometer, and skin temperature measured by a infra-red temperature sensor. It communicates the data to the MPA using the Bluetooth 2.1 communication protocol. The transmission data rates can be configured from minute averages to sampling and communication of "raw" data. A specific feature of the device is that measurement data are stored locally when there is no Bluetooth connection to the MPA, thus allowing patients to leave the phone behind when going for a walk, inside or outside the house, without any data being lost.

2) Mobile Phone with Patient Application

The purpose of the phone and phone application is threefold: 1) It enables the patient to follow-up on own measured sensor data; 2) It forwards data to the server; and 3) It acts as a concentrator for connection of other Bluetooth enabled sensor units. The system has incorporated the Nonin Medical OnyxII pulse oxygen saturation device [12] to demonstrate the integration of third party devices.

The patient application was initially developed as a Windows Mobile 6.5 application, and this implementation served all the purposes listed above. An example of patient user interface is shown in Fig. 4. A specific feature of the application is a "motivation heart" that will show on the screen when the user has reached his/hers activity and max heart rate goals of the day.

3) ESUMS Server

The ESUMS server services were installed in a VM-Ware /Glassfish application server software environment. The server offers a range of different services for sensor data measurement storage and management and user access, accessed by handheld and nurse application.

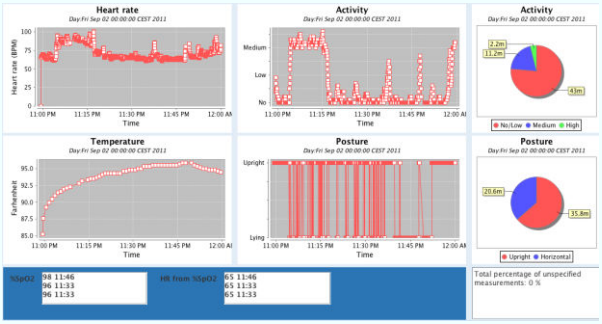

Figure 5. "Patient measurements" view of nurse application, showing detailed patient data for one day.

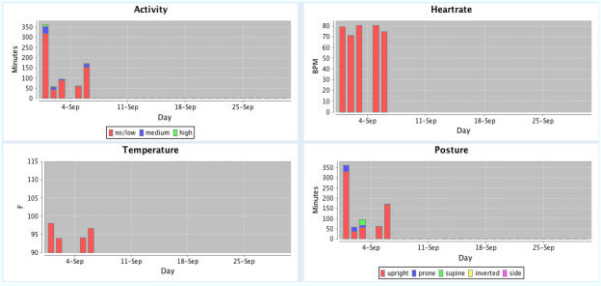

Figure 6. "Patient trends" view of nurse application, showing statistics from the last 30 days of data

4) Nurse Application

The *Nurse application* is a Java application that connects to the ESUMS server using web services. Its main purpose is to download the medical data and convey it in a useful manner to the user through the user interface. When logging in to this application the nurse receives an overview of all patients connected to the service and their overall status. Further, it is possible to study the individual patients and their recent and past monitoring history. There are two views for inspecting the detailed data, the "Patient measurements" view shown in Fig. 5 and "Patient trends" view shown in Fig. 6. The patient measurements view shows all data points for a selected day, and the trends view displays day averages of the parameters to show trends in the data for the last 30 days.

III. Testing and Evaluation

A. Performance Testing of the Wearable Device against Reference Sensors

The *Wearable Device* has been tested for accuracy against validated reference sensors by 12 healthy volunteers in controlled environments in the Work Physiology Laboratory at SINTEF, and the results are in preparation [13]. The testing displayed that the sensor device consistently gave comparable results to the validated predicates. As an example, Fig. 7 displays the average heart rate of all test subjects for the ESUMS device and the predicate Zephyr Bioharness during the 95 minute test protocol involving

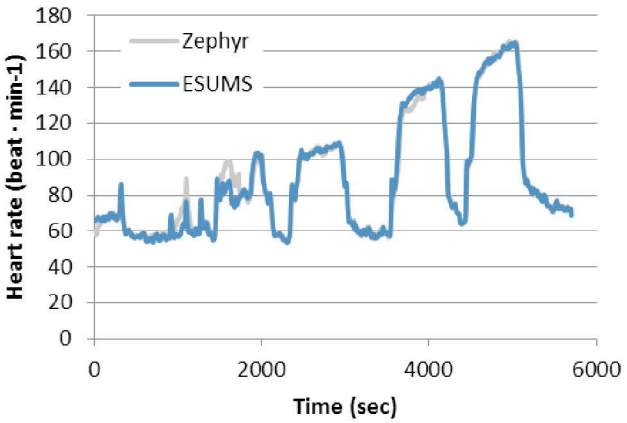

Figure 7. Average plot of heart rate for ESUMS *Wearable Device* and Zephyr Bioharness for test subjects carrying out the test protocol (n=9).

sequences of rest and various levels of activity from rest and slow walking to rigorous running.

B. Usability Testing by Congestive Heart Failure Rehabilitation Patients in Home Environments

The complete ESUMS system as outlined in Figure 1 has been usability tested in a field trial in Spartanburg, South Carolina, US [13]. The test involved 5 CHF patients and their nurses, and each patient used the system day-time for at least 14 days following discharge from hospital care for their CHF condition. In total, more than 600 hours of data were logged during the trail. Overall, the patients were pleased with using the ESUMS Wearable Device, but they had problems with using the mobile phone terminals. The latter was mainly due to relatively small screens and inherent phone issues, and to less degree due to issues with the ESUMS system itself. The nurses found that the system with continuous activity measurements offered them a significantly improved basis for discussing disease condition with the patients.

IV. Conclusion

An overall description of the Enhanced Sustained Use Monitoring System has been given. The system has been designed for remote monitoring of rehabilitation patients, and has been evaluated for accuracy and usability in this respect. The potential for using the ESUMS system, or components thereof, in other applications are currently being investigated.

Acknowledgment

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Human Subjects Testing Approvals

Both the sensor accuracy study and the usability study have been reviewed and approved by the relevant medical research ethics review boards. Further, both studies have been reviewed and approved by the U.S. Army Medical Research and Materiel Command (USAMRMC), Office of Research Protections (ORP), Human Research Protection Office (HRPO).

References

1. Radhakrishnan, K. and C. Jacelon, *Impact of Telehealth on Patient Self-management of Heart Failure A Review of Literature.* Journal of Cardiovascular Nursing, 2012. **27**(1): p. 33-43.
2. DelliFraine, J.L. and K.H. Dansky, *Home-based telehealth: a review and meta-analysis.* Journal of Telemedicine and Telecare, 2008. **14**(2): p. 62-66.
3. Pare, G., M. Jaana, and C. Sicotte, *Systematic review of home telemonitoring for chronic diseases: The evidence base.* Journal of the American Medical Informatics Association, 2007. **14**(3): p. 269-277.
4. *Newham Whole System Demonstrator (WSD) trial*. Available from: http://www.newhamwsdtrial.org/wsd-trial/.
5. Dickson, V.V. and B. Riegel, *Are we teaching what patients need to know? Building skills in heart failure self-care.* Heart & Lung, 2009. **38**(3): p. 253-261.
6. Patel, S., et al., *A review of wearable sensors and systems with application in rehabilitation.* Journal of Neuroengineering and Rehabilitation, 2012. **9**.
7. Johnstone, J.A., et al., *Bioharness (TM) multivariable monitoring device. Part I: Validity.* Journal of Sports Science and Medicine, 2012. **11**(3): p. 400-408.
8. Anliker, U., et al., *AMON: A wearable multiparameter medical monitoring and alert system.* Ieee Transactions on Information Technology in Biomedicine, 2004. **8**(4): p. 415-427.
9. Schmidt, R., J. Habetha, and M. Harris, *MyHeart - Fighting cardio-vascular diseases by prevention and early diagnosis*. Healthinf 2008: Proceedings of the First International Conference on Health Informatics, Vol 1, ed. L. Azevedo and A.R. Londral. 2008. 296-300.
10. Marius Mikalsen, S.H., Thomas Fuxreiter, Ståle Walderhaug, Leendert Wienhofen ed. *Interoperability Services in the MPOWER Ambient Assisted Living Platform*. BookStudies in Health Technology and Informatics. Vol. 150: Medical Informatics in a United and Healthy Europe: Proceedings of the twenty-second International Conference on Medical Informatics Europe MIE 2009. 2009. 366 - 370.
11. *MPOWER Open Source*. Available from: http://sourceforge.net/projects/free-mpower/.
12. *Nonin Medical Inc. OnyxII pulse oximeter.* . Available from: http://www.nonin.com/PulseOximetry/Fingertip/Onyx9560
13. *Paper in preparation*