REQUIREMENT ANALYSIS CONCERNING THE INTEGRATION OF 3D LEG OEDEMA DETECTION IN THE HOMEMONITORING OF HEART FAILURE PATIENTS

Hayn D[1], Falgenhauer M[1], Riedel A[2], Fruhwald F[2], Schreier G[1]

Abstract

Heart failure is a common disease of older people, providing high re-admission rates after hospital discharge. Though home monitoring can reduce the re-admission rate, detection of severe events needs to be improved, e.g. using new sensors for oedema detection. We describe the requirements for integrating a 3D image based leg oedema detector in an existing home monitoring scenario. Three major aspects are suggested: integration of the sensor in a body weight scales; enhanced alarm generation based on body weight and leg geometry; and adaptions of the physician's Web-interface.

Keywords – ***Heart failure, home monitoring, sensor, leg oedema, eHealth***

1. Introduction

Heart failure is a common cardiac disease in elderly patients, which induces 26,000 hospital stays each year in Austria (5 % of all hospital admissions) and it is responsible for 2 % of Austria's health budget [1]. After discharge, approximately 50 % of all patients are re-admitted to hospital within 6 months [2-4].

Recent studies show that home monitoring of heart failure patients can reduce the number of re-admissions of heart failure patients after discharge from hospital by up to 50 % [5]. Still, a large number of false positive alarms (i.e. low specifity) as well as underdiagnose in other cases (i.e. low sensitivity) require more accurate alarm generation algorithms, e.g. by including new kinds of sensors in existing home monitoring scenarios.

Leg oedemas are a common symptom in right-sided heart failure. And they are an early sign in case of cardiac decompensation. Leg oedema detection is currently done by a) optical and manual control of the feet and b) body weight monitoring. While manual control lacks objective measures and is highly dependent on the individual behaviour of the patient, body weight monitoring exhibits limited sensitivity and first of all low specifity in terms of leg oedema detection.

[1] Safety and Security Department, AIT Austrian Institute of Technology GmbH, Graz
[2] Department of Internal Medicine, Division of Cardiology, Medical University of Graz

Currently, no sensor for leg oedema detection in home monitoring settings is available. Manual leg edema quantification shows high variations depending on the method used and it shows high inter observer variability [6, 7]. Other approaches based on tissue impedance measurement are currently mainly used for lung oedema measurement [8]. Our approach was inspired by Elbischger et al. [9] who described a 3D image based approach for quantification of swelling of knees after surgeries, which we applied to leg oedema detection.

Within the project *Innovative Sensorik zur Quantifizierung kardialer Regelungsmechanismen bei Herzinsuffizienz (HI-Sens)* a prototypical leg oedema sensor has been developed in the years 2011 and 2012. The present paper describes how such an image based sensor could be integrated in state-of-the-art home monitoring systems for heart failure patients.

2. Materials and Methods

2. 1. Home monitoring for heart failure patients

The present work is based on the existing AIT home monitoring system for heart failure patients, which is currently used in several studies in Austria and Portugal [5, 10]. The system consists of

- a mobile phone-based home terminal, which collects data from a body weight scales and a blood pressure meter, and which allows the patient to manually enter medications and subjective wellbeing
- a data centre which receives the data from the home terminal through secure channels and which stores all data and provides automated data analysis
- a web-based interface for physicians, providing all home-monitoring data including threshold violations and other relevant events

In previous studies we have already tried to reduce the number of false positive alarms as generated by this system [11], but up to now, sensitivity and specifity still need to be improved.

2. 2. Oedema detection prototype

The system described in chapter 2.1 was intended to be extended by a leg oedema detector as developed within the HI-Sens project. The sensor was based on the 3D gaming console sensor Microsoft Kinect© and took colour- and depth images of patients while measuring their body weight on a standard body weight scales. Up to now, the sensor is connected to a standard personal computer, which also served as the user interface and which was used for calculating parameters that were identified to be relevant for oedema detection.

Figure 1 – Illustration of the sensor system, consisting of 3D camera and body weight scales (taken from [12])

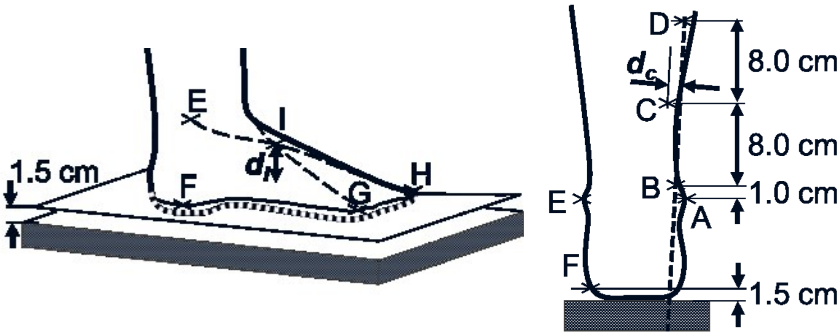

Figure 2 – Illustration of reference points and oedema parameters. Left: Instep height d_i was defined as the distance of point *I* (crossing point of *AG* and *EH*) to the surface through *F, G* and *H*. Right: Lower leg curvature d_c was approximated as the distance from point *C* to the line through *B* and *D* (Figure taken from [12])

Details concerning the sensor system are described in [12]. An illustration of the sensor is shown in *Figure 1*. Parameters quantified by the system are illustrated in *Figure 2*.

3. Results

3. 1. Integration of the oedema detector in a body weight scales

In order to integrate the leg oedema detector in an unobtrusive way, no additional measurement device should be provided to the patient. Furthermore, extra buttons or other user interfaces and additional user interactions should be avoided. Therefore, we suggest to integrate the 3D camera in a standard body weight scales. By that, the camera could be triggered by the body weight scales, i.e. the photo could be taken at the moment the scales identifies a steady-state (which is already done in order to trigger the measurement of the body weight).

The camera we used in [12] required a minimum distance from the camera to the subject of approximately 70 cm. Therefore, in order to integrate the camera in a body weight scales, the optical system of the camera needs to be adapted, so that the minimum distance can be reduced to 10 cm, e.g. by the use of a commercially available play range reduction lens (*Zoom*, Nyko, Los Angeles, CA, USA).

There are several interesting points on the patient's leg that should be included in the image, such as inner and outer ankle, toes and instep. Therefore, it is essential that the camera is positioned in a way that all these points can be seen on the image. Since moving elements are suggested to be avoided, the optimal position of the camera is suggested to one of the front corners (on the toe-side of the foot), elevated high enough in order to see the upper side of the instep, since all relevant points can be seen from that perspective – either on one or on the other leg.

Cameras in patient homes – especially in bathrooms, are unacceptable in terms of privacy and user acceptance. Therefore, it is essential, that no pictures may be stored, transmitted, or displayed. Terms such as "camera", "picture" or "photo" need to be avoided. Lenses and optical elements should be hidden to the user and the field of vision should mechanically be limited as much as possible. Additionally, due to the 3D camera, it is possible to restrict the region which can be seen by the camera to a 3D square which can be defined right upon the body weight scales with a height of no more than 50 cm. By that, it can be assured that nothing but the patients legs can be seen by the sensor.

3. 2. Data interpretation and user interface

Looking at the data provided by the sensor described, consisting of a body weight scales and a 3D imaging system, new methods are needed in order to decide, whether an oedema is present or not. It is important to notice, that oedema detection from absolute values is unlikely to be working appropriately, since leg geometry is highly depending on the individual patient. Nevertheless, changes in leg geometry can be correlated with leg oedema – especially when combined with the body weight. *Table 1* summarizes possible changes in weight and leg geometry, as well as suggested reactions as required by the home monitoring system.

Table 1 – Interpretation of leg geometry based on 3D imaging and body weight in terms of oedema detection

	Leg volume		
Body weight	increasing	constant	decreasing
increasing	Leg oedema alarm	Borderline	No leg oedema alarm *(lung edema? nutrition?)*
constant	Borderline	No leg oedema alarm	No leg oedema alarm
decreasing	No leg oedema alarm *(leg injury?)*	No leg oedema alarm	No leg oedema alarm

Based on the parameters illustrated in *Figure 2* (instep height; curvature of the lower leg) and similar geometric measures, an oedema score should be calculated and this score should be shown on the display of the extended scales, additionally to the body weight. Since absolute values of an oedema score are of limited value (see chapter 3.2) a timestamp needs to be recorded in order to provide a possibility for monitoring of the evolution of the oedema score over time. Additionally, we suggest not only to display the present value, but also the trend of the oedema score. Since heart failure patients are used to measuring their blood pressure, the design of the display is suggested to be based on that of common blood pressure meters, displaying systolic and diastolic blood pressure as well as heart rate. An example is illustrated in *Figure 3*.

Figure 3. Display of an extended body weight scales with leg oedema score (left) as compared to the display of a state-of-the-art blood pressure measurement device (right).

3. 3. Integration in a home monitoring scenario – The physician's point of view

Figure 4 shows our suggestion for extending the current version of the physician's Web-based user interface to the AIT home monitoring system. The evolution of the oedema parameter over time is plotted in the same graph as the body weight, since it is expected that the combination of these two parameters is most significant in terms of oedema detection and differentiation in between normal and abnormal changes of body weight and leg geometry.

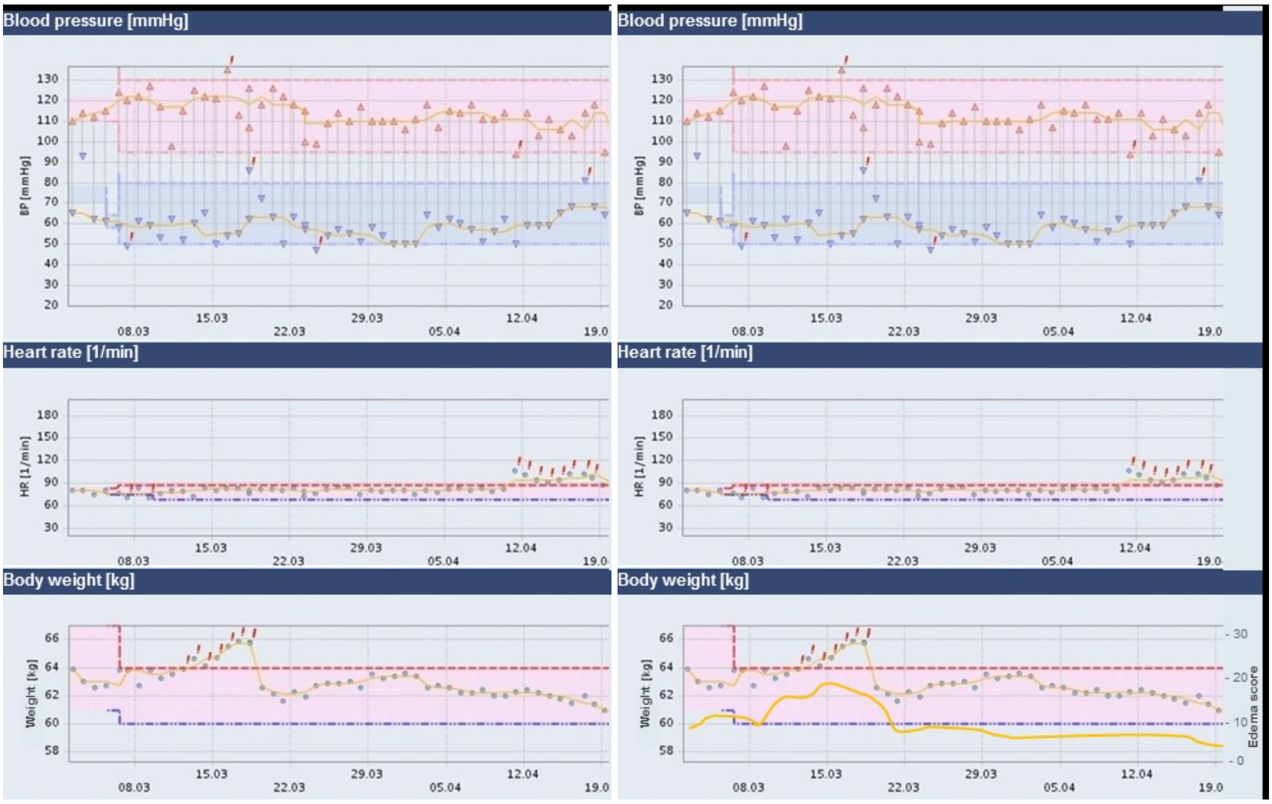

Figure 4 – Screenshot of graphical data representation as currently provided to the physician (left) and including suggested oedema parameter evolution (right). Oedema parameters (yellow line) are plotted in the same graph as body weight in order to provide a clear view of these two parameters. Red exclamation marks represent alarm as generated by the present system. Shaded areas show the target region of the respective parameters. Please note that oedema data are imaginary only, since up to now no real-life data are available.

4. Discussion

We described the requirements that need to be fulfilled for integrating a 3D leg oedema detector in an existing home monitoring system for heart failure patients. We found that hardware development is only the first step in extending such a system by a new sensor. Three major focuses have been identified (hardware, data interpretation and physician's user interface) and solutions for these three aspects have been described.

Up to now, leg oedema detection based on 3D images is in a very early stage. It is not known yet whether this concept a) is precise enough, b) is stable enough and c) provides a short enough time delay concerning the detection of severe events of heart failure patients in order to successfully enhance existing home monitoring systems. In an on-going study, we are currently evaluating the changes in 3D oedema parameters as recorded by a prototypical camera system at patients, who are treated as an inpatient at the Medical University of Graz after cardiac decompensation due to heart failure with significant leg oedema. In this study we monitor the reduction of leg oedema and its effect on instep height and lower leg curvature as measured from the 3D images. Results are expected for summer 2013.

Based on the results of this study, the next step will be to implement the concept illustrated in the present paper, and to test our approach in a real life scenario. Thereafter we hope to know, whether

3D imaging can improve sensitivity and specifity of alarm generation algorithms and – as the final aim – detect possible problems earlier than existing systems and further reduce the number of severe events during home monitoring of heart failure patients.

5. Acknowledgements

This work was supported by the Styrian government, department 3, science and research [grant number A3-22.H-2/2011-11].

6. References

[1] Jahrbuch der Gesundheitsstatistik 2006, Statistik Austria.

[2] Komajda M, Follath F, et al. The euroheart failure survey programme – a survey on the quality of care among patients with heart failure in Europe. Part 2: treatment. Eur Heart J 2003; 24(5):464-474.

[3] Krumholz HM, Parent EM, et al. Readmission after hospitalization for congestive heart failure among medicare beneficiaries. Arch Intern Med 1997; 157: 99-104.

[4] Martinez A, Everss E, et al. A systematic review of the literature on home monitoring for patients with heart failure. Journal of Telemedicine and Telecare 2006; 12: 234–241.

[5] Scherr D, Kastner P et al, and the MOBITEL investigators. Effect of Home-Based Telemonitoring Using Mobile Phone Technology on the Outcome of Heart Failure Patients After an Episode of Acute Decompensation: Randomized Controlled Trial, J Med Internet Res 2009; 11(3):e34 URL: http://www.jmir.org/2009/3/e34/

[6] Perrin M. Edema and leg volume: methods of assessment. Angiology. 2000 Jan;51(1):9-12.

[7] Brodovicz KG, McNaughton K, Uemura N, Meininger G, Girman CJ and Yale SH. Reliability and Feasibility of Methods to Quantitatively Assess Peripheral Edema. Clinical Medicine & Research 2009. 7(1/2): 21-31

[9] Elbischger P, Jerolitsch-Binder J, Prasser M, Menard C. Ein neuartiges Messsystem zur Exakten und effizienten Ermittlung des Extremitätenvolumnes. In: Schreier G, Hayn D, Ammenwerth E, editors. Proceedings of the eHealth2011. 26.-27. Mai 2011; Wien. OCG 2011:129-134. URL: http://www.ehealth20xx.at/eHealth2011/papers/elbischger.pdf

[10] Kastner P, Morak J, Modre R, Kollmann A, Ebner C, Fruhwald FM, Schreier G. Innovative telemonitoring system for cardiology: from science to routine operation. Appl Clin Inf 2010; 1: 165–176 http://dx.doi.org/10.4338/ACI-2009-12-RA-0021

[11] Vuković M, Drobics M, Hayn D, Kastner P, Schreier G. Optimization of the alarm-management of a heart failure home-monitoring system. Computers in Cardiology 2010. 37:53-56.

[12] Hayn D, Raschhofer S, Falgenhauer M, Modre-Osprian R, Fruhwald F, Schreier G. Edema Detection for Heart Failure Patients in Home Monitoring Scenarios. Comping in Cardiology 2012. 39:93-96.

Corresponding Author
Dieter Hayn
Safety and Security Department, AIT Austrian Institute of Technology GmbH
Reininghausstr. 13/1, A-8020 Graz, Austria
Email: dieter.hayn@ait.ac.at