# Edema Detection for Heart Failure Patients in Home Monitoring Scenarios

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## Abstract

*Heart failure consumes 2% of Austria's health budget. Re-hospitalization rates within 6 months after discharge are about 50% and earlier studies showed that even telemonitoring can only avoid up to 50% of these re-hospitalizations. Since leg edemas are a typical symptom, it was our aim to further reduce this rate, using new methods for edema detection.*

*An existing telemonitoring system was extended by a 3D camera in order to geometrically detect and quantify leg edemas. 3D images were taken and instep height and leg curvature, were calculated. We present the results of the first evaluation step – a feasibility test, comparing relative intra-subject variations.*

*A total of 87 measurements at different times of day within four consecutive days were performed for five healthy subjects. Relative intra-subject variation V_rel was 2.89±0.90% for instep height and 8.32±0.77% for leg curvature.*

*Our results indicate that by 3D imaging, the geometry of a person's foot can be measured with errors that are far lower than changes expected in case of edemas. Instep height and leg curvature were found to be reliable parameters for the monitoring of legs. Future work will investigate whether edemas can be detected by our method and evaluate the concept's usability in a real-life home monitoring scenario.*

## 1. Introduction

### 1.1. Telemonitoring during heart failure

Heart failure induces 26,000 inpatient hospital stays per year in Austria and consumes 2% of its health budget [1]. Worsening of heart failure is responsible for 5% of all hospital admissions and re-hospitalization rates within 6 months after discharge are about 50% [2-4]. Earlier studies showed that even telemonitoring can only avoid up to 50% of these re-hospitalizations [5] and a large number of re-hospitalizations remains. Since leg edemas are a typical symptom especially for right-sided heart failure, it was our aim to find new methods for edema detection that can be applied in telemonitoring scenarios at reasonable costs, in order to

a) further reduce the re-hospitalization rate and
b) reduce the number of false positive alarms

when applied to a telemonitoring scenario.

### 1.2. Edema detection – State-of-the-art

Edema can be detected in various ways. A common approach widely used in home-monitoring scenarios is control of patients' body weight. Fluids accumulated in lungs and/or legs are caused by a water misbalance due to less water excretion than consumption. This leads to an increase of body weight. Critical values for heart failure patients are an increase of 2 kg within 2 consecutive days. Since body weight depends on several other parameters (e.g. eating and drinking behaviour), edema detection based on body weight is rather unspecific – leading to a large amount of false positive alarms [6].

Lung edema – a typical sign in left sided heart failure – can be detected with impedance based detectors as nowadays included in implantable cardiac rhythm management devices. Via impedance measurement different types of tissue such as fat, muscle, air (within the lungs) or water (as present in case of edema) can be distinguished. [7, 8] describe such an impedance based approach for lung edema detection within implanted devices. Impedance based edema detection is currently only available for implantable devices and it can only be used for lung edema detection.

During right sided heart failure, edema appear in the legs rather than in the lung. Leg edema lead to swelling of the legs. Quantification of leg edema can be done by measuring the circumference of the leg – either in one surface or by the *figure-of-eight* method. Unfortunately, all of these methods provide limited reliability and high inter observer variability. Water displacement is often used as the gold standard. Unfortunately, due to the high degree of manual interaction none of these methods is suitable for self-measurement in home monitoring scenarios. A comparison of state-of-the-art methods for leg edema quantification is given in [9].

Based on a work of Elbischger et al. [10] it was our idea to use 3D imaging for edema detection. Novel 3D cameras such as the Kinect (Microsoft Corporation, Redmond, WA) are able to take high resolution three dimensional images for very reasonable costs. While Elbischger et al. used such images for geometrical knee survey after surgery, it was our aim to adapt their approach in order to detect leg edema.

## 1.3. Objectives

The aim of the present work was to prototypically develop a low-cost semi-automatic leg edema detection system based on 3D imaging, suitable for home monitoring scenarios, and to evaluate its reliability by testing the intra-subject variability of edema parameters when calculated for healthy subjects.

## 2. Methods

A well-established (>120 patients by April 2012) telemonitoring system consisting of blood pressure meter and body weight scales [11] was extended by a 3D camera in order to geometrically detect and quantify leg edema.

The parameters extracted from the 3D images and the reference points used are described in section 2.1. Thereafter, the sensor system and image processing software are described in section 2.2. Finally, in section 2.3, we describe the study we conducted in order to evaluate parameter intra-subject variability.

## 2.1. Edema parameters

During discussions with clinical heart failure experts, two independent geometric parameters were identified, which were expected to change already in an early stage of leg edema:

- instep height
- curvature of the inner lower leg right above the inner ankle

In order to determine these parameters from 3D images of the patients' legs, 9 reference points on the leg were defined:

*A* most elevated point of the inner ankle

*B, C* and *D*
1, 9 and 17 cm above *A* along a straight line from *A* to the apex of the patella

*E* most elevated point of the outer ankle

*F* vertically underneath E, 1.5 cm above the surface of the scales

*G* capitulum of the outer most metatarsal bone, 1.5 cm above the surface of the scales

*H* tip of the big toe, 1.5 cm above the surface of the scales

*I* middle of the instep at the crossing point of lines *AG* and *EH*

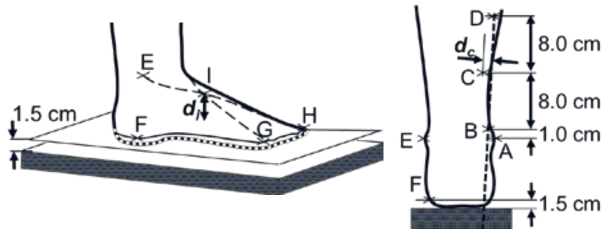


Figure 1. Illustration of reference points and edema parameters. Left: Instep height $d_i$ was defined as the distance of point *I* (crossing point of *AG* and *EH*) to the surface through *F*, *G* and *H*. Right: Lower leg curvature $d_c$ was approximated as the distance from point *C* to the line through *B* and *D*.

Instep height was calculated as the distance of point *I* to the surface *FGH*. Lower leg curvature was approximated by the distance from *C* to line *BD* (see also chapter 2.2, Equations 1-3).

An illustration of the reference points and distance parameters is shown in Figure 1.

## 2.2. Sensor system

A prototypical sensor system was developed based on the 3D gaming console sensor Kinect. By means of its integrated colour- and depth-cameras images of subjects standing on a body weight scales were taken. The sensor was connected to a standard personal computer that triggered image recording and stored 3D data of the subjects' legs as well as colour information of the image. An illustration of the sensor system is provided in Figure 2.

Figure 2. Illustration of the sensor system, consisting of a 3D camera in combination with a body weight scales.

Data provided by the Kinect were not calibrated and no calibration was done by our software. Instead, we decided to validate the robustness of our algorithms by analysing only relative values of the measures calculated.

Since the geometric adjustment of camera, body weight scales and legs (standing on the scales) was fixed for all recordings, the recording depth window was constricted to the region of the scales. Image analysis was done using Blender 2.49b (Blender Foundation, Amsterdam, The Netherlands). 3D image and colour information were overlaid and the reference points as defined in chapter 2.1 were selected manually.

Instep height was calculated as the distance of point I to the surface *FGH* according to Equation 1.

$$d_i = \frac{\overrightarrow{FG} \times \overrightarrow{FH}}{|\overrightarrow{FG} \times \overrightarrow{FH}|} \circ \overrightarrow{FI} \qquad (1)$$

The curvature of the inner lower legs right above the inner ankle was approximated by the distance of point *C* from the line through *B* and *D*, which was calculated according to Equation 2.

$$d_c = \frac{|\overrightarrow{BC} \times \overrightarrow{BD}|}{|\overrightarrow{BD}|} \qquad (2)$$

Equations 1 and 2 provide distance information without consideration of orientation. While the orientation of $d_i$ was not of interest (the instep height is always positive), orientation of $d_c$ might be essential, since in case of edemas lower leg curvature is expected to change from concave to convex. Therefore, orientation of $d_c$ was calculated based on the knowledge, that due to the geometric arrangement of the sensor, the camera had the coordinates (0,0,0) and it was always situated in front of the leg. Hence, the decision concerning convex or concave was done according to Equation 3.

$$curvature = \begin{cases} convex \ldots\ldots if \ (\overrightarrow{BC} \times \overrightarrow{BD}) \circ \overrightarrow{OB} > 0 \\ concav \ldots\ldots otherwhise \end{cases} \qquad (3)$$

*with O = (0,0,0)*

## 2.3. Intra-subject variability study

Our system has been validated in a study testing the intra-subject variability of both parameters when applied to healthy subjects up to two times per day on four consecutive days. On day one, optical markers were painted on the leg at the reference points described in chapter 2.1, using a water resistant pen. On subsequent days these markers have been refreshed if necessary.

3D images were taken and reference points as defined in chapter 2.1 were selected within the images manually. Instep height $d_i$ and inner lower leg curvature $d_c$ were calculated for each measurement.

For each subject, the relative intra subject variabilities *RSD* ($d_i$) and *RSD* ($d_c$) were calculated as relative standard deviations according to Equation 4.

$$RSD(X) = \frac{STD(X)}{MN(X)} * 100 \ [\%] \qquad (4)$$

## 3. Results

A total of 87 measurements at different daytimes within four consecutive days were performed for five male healthy subjects in the age range of 25 to 35 years. Four files ($d_i$) and 8 files ($d_c$) could not be evaluated since the 3D image files were defected (2 files) or the exact position of one or more markers was not visible (others).

Manual image preparation and marker selection took less than 15 min per image.

Intra subject variability for $d_i$ and $d_c$ for each single subject are summarized in Table 1. All curvatures were concave.

Table 1. Intra-subject variability of instep height $d_i$ and inner lower leg curvature approximation $d_c$

| | RSD ($d_i$) [%] | RSD ($d_c$) [%] |
|---|---|---|
| Subject 1 | 1.51 | 9.43 |
| Subject 2 | 2.94 | 7.65 |
| Subject 3 | 2.62 | 7.54 |
| Subject 4 | 3.53 | 8.43 |
| Subject 5 | 3.81 | 8.55 |
| **Mean** | **2.89** | **8.32** |
| **Standard deviation** | **0.90** | **0.77** |

## 4. Discussion

We have developed a prototypical sensor system for 3D imaging based edema detection. The system was validated with five healthy subjects.

As can be seen from Table 1, intra-subject variability was significantly lower for instep height $d_i$ than for inner lower leg curvature $d_c$. Based on discussions with experts in the field of heart failure monitoring we assumed that in case of leg edema *RSD* ($d_i$) would be higher than 10 % and *RSD* ($d_c$) higher than 50 %. Therefore, for both parameters intra subject variability was far lower than changes expected during cardiac decompensation, indicating that 3D imaging is suitable for detection of leg edemas.

Up to now, the whole system is implemented only very prototypically in order to enable the evaluation of the parameters of interest. The final measurement device is intended to consist of a body weight scales with integrated 3D camera and automated image processing. Currently, selection of the reference points a) was based on markers painted on the subject's skin and b) they were selected manually from the 3D images, which is a rather time consuming task that can only be done by skilled personnel with special image processing software. We expect that reference point selection can be done reliably by fully automated image processing algorithms, but this has not been investigated yet. No information is available, whether the reliability will be reduced in case of fully automated measurement.

Camera based sensor systems are of limited suitability for telemonitoring scenarios (“Big Brother effect”). Using our approach, it is possible to store, display and transfer only the parameters calculated from the images but not the images themselves. Additionally, even if images are used, 3D images have the advantage, that the region within the patient’s home that is seen by the camera can be restricted in all three geometric dimensions (even depth), so that only the volume right above the body weight scales, e.g. from foot to knee of the patient, needs to be recorded.

In the present study we could show that edema relevant geometric parameters can be calculated using a 3D imaging system with low intra subject variability for healthy subjects. Still this is only the first step.

Future steps will be to study whether our measurement parameters are correlated to the severity of leg edemas. For this purpose, a clinical study is planned to commence in autumn 2012. Heart failure patients admitted to hospital with leg edemas due to cardiac decompensation will be monitored during their hospital stay. Edema *reduction* during the treatment in the hospital will be analyzed and the correlation of our measures with a golden standard will be evaluated.

Finally, based on that edema *reduction* study, our method needs to be evaluated in a real-life home monitoring scenario, analyzing its usability and its capability to detect the *development* of edemas in an early stage.

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