Application of EIT to determine bladder volume

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***Abstract*—One reason for incontinence can be inadequate perception of bladder filling level by the patient. To support those patients, electrical impedance tomography could become an option to determine bladder volume continuously and non-invasively as a feedback to the patient for bladder accumulation training or to determine the right time for self-catheterization.**

I. Introduction

Often neurologic diseases like paraplegia or age-related diseases like diabetic neuropathy result in inadequate perception of bladder filling level due to destroyed nervous structures. In succession, this leads to incontinence, since the patient misses to go to toilet when the bladder is full. Quality of life for the patient is decreased and the care requirements are drastically increased. For patients with paraplegia, who can not control their bladder emptying, a frequent solution is the regular use of self-catheterisation, as described by Guttmann [1]. Since to date no portable monitoring device to measure bladder filling level continuously is available, patients have to follow a strict rhythm for bladder emptying, like every four hours. Drawbacks of this fixed scheme are that the bladder may be emptied when not necessary or that the emptying might come too late, resulting in damages to the urogenital tract due to an overfull bladder. A device continuously measuring and showing bladder volume on a display will help the patients to install a more flexible, demand-driven emptying scheme. Such a monitoring device could also help patients with overactive bladder syndrome (OAB) to train their bladder to hold more urine. OAB patients feel a sudden and urgent need to urinate, even when the bladder is only partially filled. By successively trying to hold the urine longer, bladder storage capacity could be increased.

A common technique to measure bladder volume today is by ultrasound examination, but continuous measurement is not possible and the accuracy is depending highly on the skills of the examiner [2]. One way for portable, continuous bladder volume measurements could be by impedance measurement, as addressed in the next section. A concept of a portable, continuous bladder volume monitoring system is depicted in Fig. 1. The electrodes required for the measurements can be embedded in a pair of pants, thus ensuring correct positioning even for technically unskilled nursing personnel. An electrode cable can then interface the pants with a measurement device, either mounted on the wheel-chair for paraplegic patients or worn around the waist. The calculated bladder filling level could then be shown on a smartphone or watch.

On our way towards a portable bladder volume monitor, this paper will focus on regional impedance measurements using electrical impedance tomography.

The article is structured as follows: In section II a brief overview of the work related to bladder volume measurement by means of electrical impedance is given. The clinical measurement setup is described in sec. III and the algorithms used for impedance calculation from the electrical impedance tomography images are presented in sec. IV. The paper is concluded with a presentation of the results in sec. V and a final conclusion in sec. VI.

II. Bladder volume monitoring by impedance measurement

First steps towards a bladder filling gauge have been performed by Talibi et al. in 1969 [3]. They applied four electrodes directly to the bladder wall and could show a linear dependency of impedance and filling level. Waltz et al. reproduced the results in 1970 [4]. While the first measurements used electrodes placed directly to the bladder wall, Denniston showed that the linear impedance trend is retained when measuring non-invasively by electrodes attached to the

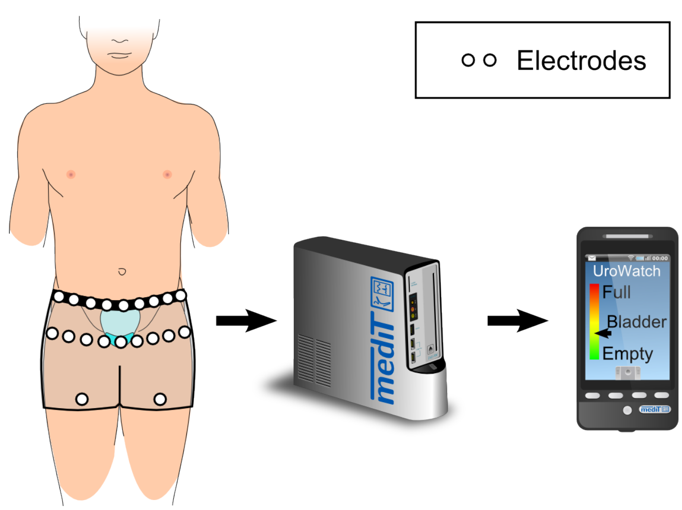

Fig. 1. Proposed textile integrated system for bladder volume monitoring.

skin [5]. For his measurements, metallic braid electrodes were placed around the thorax of six dogs. The first ring electrode was placed cranial of the xiphoid, the fourth ring electrode around the proximal portion of each hind limb. Although the spatial sensitivity covered more or less the complete lower thorax, good correlation of impedance change and bladder volume could be shown. The results with dogs could be proved also to be valid for humans by Doyle in 1975 [6] and Kim in 1998 [2].

One problem of non-invasive impedance measurements is, that only an overall impedance is measured that can be influenced from a wide variety of factors. Liao et al. showed an influence of body composition on the measurements, Doyle and Gill noticed an influence of temperature and body posture [7], [6], [8]. Also fluid and faecal movements or accumulation in the rectum could influence the overall impedance [2].

To limit the averaging effect, Hua et al. suggested to use multiple electrodes attached to the anterior body surface [9]. Computer simulations showed an increased impedance change for this electrode position due to better spatial sensitivity.

Since electrical impedance tomography (EIT) calculates the spatial distribution of impedance in a cross sectional area, the sensitivity to bladder changes could be further increased by identifying only the impedance change in a predetermined region of interest, where the bladder is expected.

In the course of this paper we would like to discuss how non-invasive bladder impedance measurements can be enhanced by accounting only for impedance changes in a predetermined region of interest.

III. Clinical measurement setup

Impedance recordings from nine male paraplegic patients from a preliminary study could be re-used [10]. In this preliminary study, an experimental EIT device (EEK2, Draeger Medical, Lbeck, Germany) was available for EIT recordings. To interface the device with the patient, a 16-electrode silicone belt was placed cranial of the hip bone and electrode contact impedance was ensured to be in the range of $100 - 300\Omega$. During regular urodynamic examination, the bladder was filled slowly with ordinary contrast fluid (Dr. Franz Koehler Chemie GmbH, Bensheim, Germany). In regular intervals, the bladder filling was stopped to take a series of EIT frames.

In this work, only the general impedance of the electrical impedance tomography image has been calculated, not taking any anatomic a-priori knowledge into account [10]. However, the results showed a good linear correlation of general impedance.

IV. Data analysis

Since electrical impedance tomography provides information about regional impedance distributions, accuracy could be enhanced by accounting only for impedance changes in a predetermined region, where the bladder is expected. Two approaches to determine a region of interest have been evaluated: The first approach uses a fixed, quadratic region of interest placed ventral in the image, as shown in the lower middle plot in Fig. 3. Impedance changes in white areas are included in the calculations, while black parts are set to zero impedance change. The other approach generates the region of interest mask from the image data by the following steps:

1) Measure reference images for a patient with empty and completely filled bladder
2) Reference the image for full bladder to the image with empty bladder, resulting in an image where the bladder-related impedance change is dominating (see Fig. 2)
3) Calculate the greatest per-pixel impedance change in the image ΔZ_{max}
4) All pixels with impedance change $\Delta Z_i \geq \Delta Z_{max}/2$ form the region of interest (see lower right picture in Fig.3)

The impedance images are then masked with this region of interest prior to calculating the general impedance change in an image.

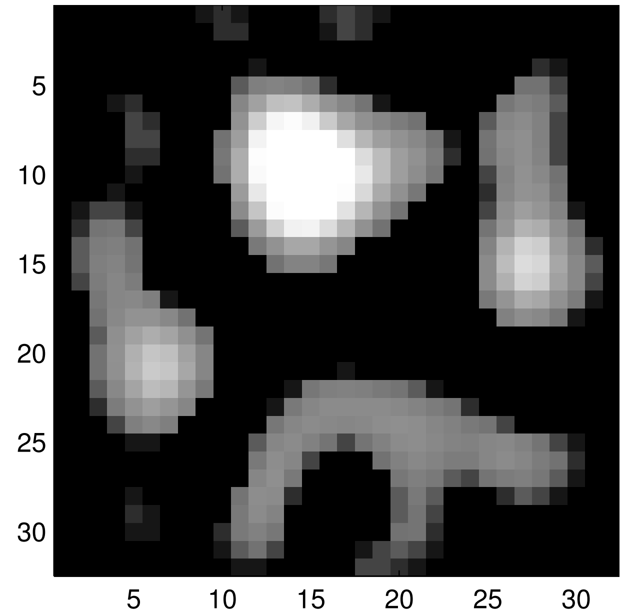

Fig. 2. Image of full bladder referenced to empty bladder.

V. Results

Results of the impedance change during urodynamics are shown for one exemplary patient in Fig. 3. The upper graphs show the impedance change over time, while the lower graphs show the region of interest used for the upper plot. In general, the linear impedance trend occurs also when taking the whole image into account (left). Using a simple, quadratic region of interest (middle) can reduce perturbing influences (like the rise around sample number 4000). When using a region of interest trained to the patient (right), further influences like breathing are reduced and the impedance stairs are clearly visible.

The reduced impedance variation within one bladder volume step is visualized as a box plot in Fig. 4. The trained bladder region of interest drastically reduces impedance variations within one volume step.

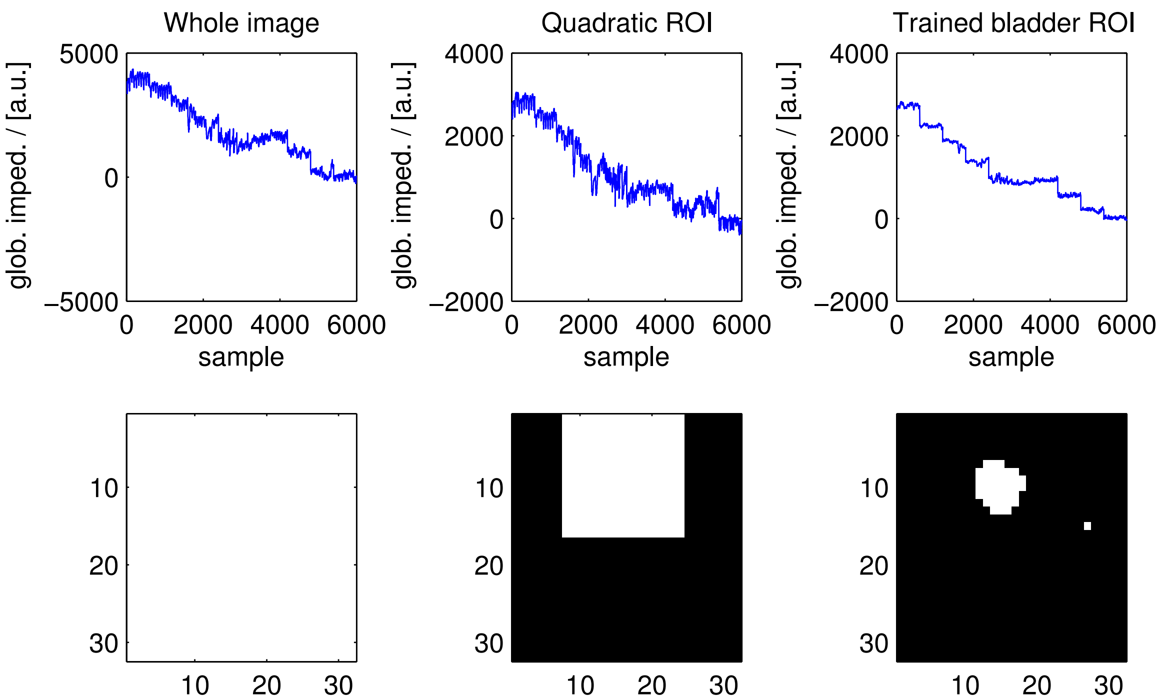

Fig. 3. Influences of the chosen region of interest on the impedance calculation.

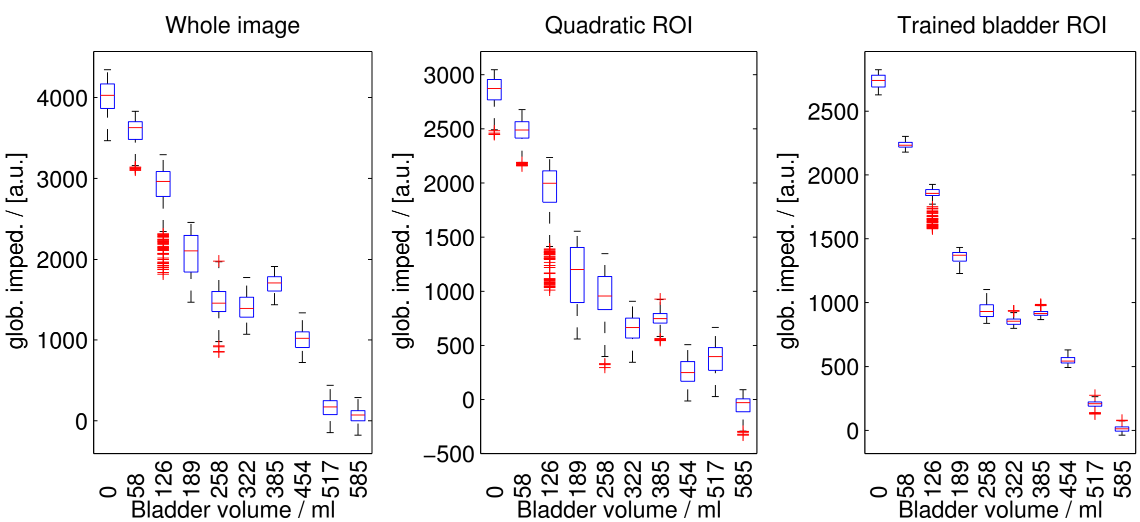

Fig. 4. Box plots showing the impedance variation within one bladder volume step during urodynamics.

VI. Conclusion

Non-invasive impedance measurement is a promising technology for a portable, continuous bladder volume monitor. Electrical impedance tomography can help to increase accuracy by providing information about the spatial distribution of the impedance changes. In this way, influences like breathing and faecal movement can be reduced. What has not been addressed yet is varying urine conductivity that could have great influence on the impedance changes, too. By taking further geometry information from the EIT-images like boundaries, volume calculation could be further enhanced, what is planned for the future.

Acknowledgment

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