A phantom based system to evaluate EIT performance

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Abstract: This work is motivated by the requirement to generate stable and accurate phantoms on which EIT systems can be calibrated and tested. Such testing is required in order to quantitatively and reproducibly validate EIT system performance. We proposed a phantom system design based on reproducible procedures with completely characterized and traceable test objects. A robotic system was used to reproduce predefined positions of targets in a saline filled tank, and a data analysis system was implemented to evaluate the image reconstruction accuracy and performance. Using this methodology, three EIT hardware systems were tested and compared.

Keywords: Electrical Impedance Tomography, Calibration, Physical Phantom

1 Introduction

Electrical Impedance Tomography (EIT) shows promise for clinical monitoring during mechanical ventilation to provide information on the distribution of ventilation in order to identify regions of lung collapse, normal ventilation and overdistribution. This work is motivated by the requirement to practically evaluate the accuracy of EIT measurements of such regional measures. In this work, we focus on EIT accuracy measures of image quality and distingushability limits for small conductivity contrasts. We do not focus on accuracy and noise measurement of the measurements themselves (such as [2–4]), or on tests of EIT image artefacts, such as those associated with body shape or electrode movement and contact quality. We present a methodology to evaluate the performance of a complete EIT system (including measurement hardware and image reconstruction), based on a saline filled tank with calibrated and reproducible test targets, and a robotic system to reproducibly and precisely position test objects at predefined positions within a saline filled tank. EIT images reconstructed from test data were evaluated in terms of image reconstruction accuracy and performance.

2 Methodology

System Description: A phantom test system was constructed using a robot, saline tank phantom, test targets and EIT measurement system. A saline phantom with 14 cm radius and 36 cm height was equipped with 4 rows of 32 electrodes. The robotic system was used to position calibrated conductivity targets within the saline solution with sequential object locations precisely controlled by a computer.

Test Phantom: In this experiment, we used a non-conductive plastic cube of 100 ml. The plastic cube has a resistivity value of much greater than 1000 $k\Omega$·cm. The tank was filled with

22 liters of saline solution with conductivity 0.8 $S \cdot m^{-1}$. When the plastic cube was moved in the saline solution according to the predefined movement protocols, the movement of the cubes caused motion of the saline solution. In order to avoid noise caused by the motion of the saline solution and subsequent object movement, a delay of 15 s was experimentally determined to be necessary before measurements could be started.

Robot design: The robotic system was constructed from standard LEGO parts using a LEGO Mindstorms system to control it. It was placed on top of the cylindrical tank to precisely position the target objects within the saline tank. The movement protocol was stored on a computer and transmitted to the robotic controllers via Bluetooth. The positions of a plastic cubic object were controlled in the X, Y and Z directions.

Protocol description: Fig. 1 shows a set of movement protocols for a single non-conductive object with vertical, circular and horizontal displacements with 12, 17 and 13 positions respectively.

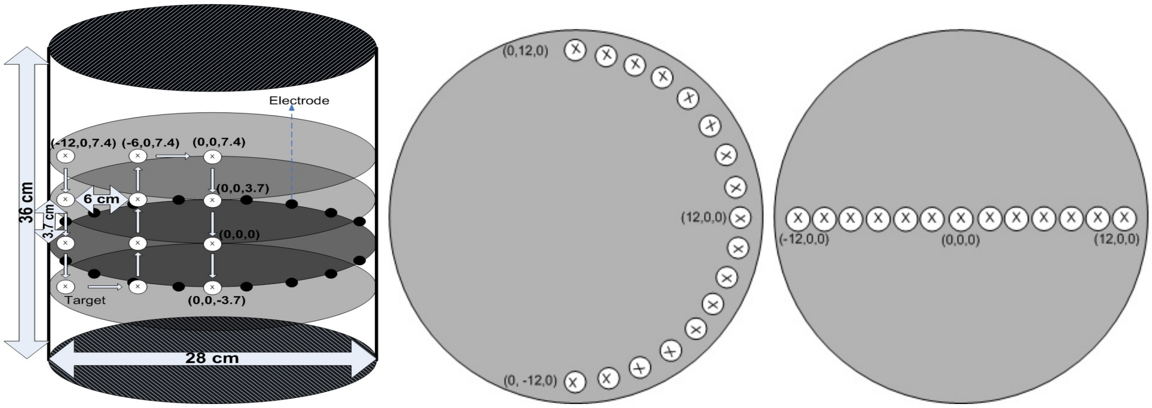

Figure 1: Schematic drawing of movement protocols of a single target object: *Left:* Vertical movement at fixed radial positions, *Middle:* Circular movement (in steps of approximately 5.5 cm of tangential distance) at fixed radial and horizontal positions, and *Right:* Horizontal movement (with 2 cm steps) in radial direction in the electrode plane.

Performance parameters: This study used the following figures of merit defined in the GREIT algorithm[1]: (i) amplitude response (AR), (ii) position error (PE), (iii) resolution (RES), (iv) shape deformation (SD), (v) non circular and ringing shape (RNG).

We developed a new *detectability* measure, DET, to measure an index of the probability of detection of a target with a given EIT system, where DET $= \frac{\bar{x}_{ROI}}{\sigma_{ROI}}$, which equals the normal (or z-) score in statistal testing. The *detectability* is thus designed to indicate the amplitude of the imaged target region and the signal to noise ratio (SNR). The signal amplitude, $\bar{x}_{ROI}$, is the mean image in a region of interest (ROI), calulated from multiple reconstructed images. σ_{ROI} represents the EIT noise amplitude, calculated from the standard deviation of multiple reconstructed images. ROI was defined as image amplitude greater than $\frac{1}{4}$ of the maximum threshold criterion. It includes the region of the reconstructed image which represents the largest contribution to the image amplitude. A ROI was selected (rather than the entire image) to avoid contamination of the noise region by image artefacts from outside of this region.

3 Evaluation

Detectability measure: Three different EIT systems (referred to as A, B and C to avoid possible unfair comparison) were evaluated. Evaluation was performed using the target movement protocol (Fig. 1). Results of performance evaluation of each defined parameter are shown in Fig. 2.

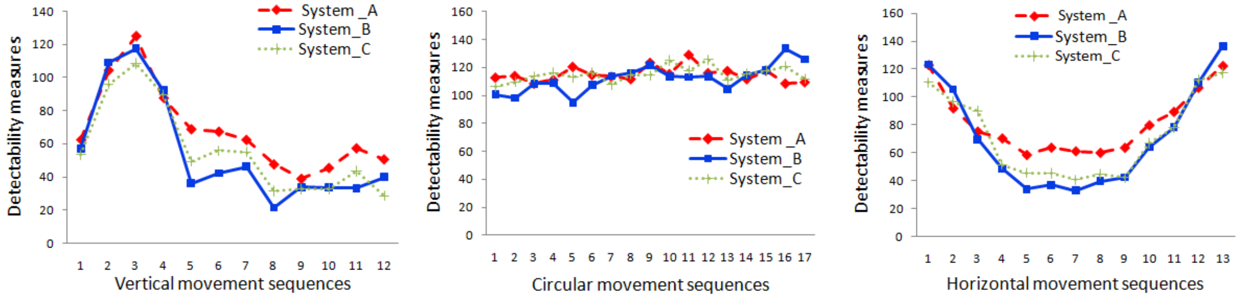

Figure 2: Evaluation of three EIT system performance with detectability of a non-conductive target with *Left:* vertical, *Middle:* circular and *Right:* horizontal displacements.

All three systems showed similar detectability for circular movement (Fig. 2:*Middle*). Since this protocol placed targets close to the edge of the tank, such large detectability values are expected. For detecting targets placed in the middle or out of the electrode plane (Fig. 2:*Left* and *Right*), peformance in rank order was systems: A, C, B.

GREIT parameter evaluation: Further comparisons of the three systems were conducted based on AR, PE, RES, RNG and SD in Fig. 3. For the best performance, it was desirable for AR, PE, RES and SD to be constant, while PE, RES, RNG and SD should be as small as possible for any target position [1]. These parameters were calculated from an average of 10 measurements for each position. It can be seen from Fig. 3 that all three systems have similar PE for the target with vertical and horizontal movement in different positions, while circular movement of the target produced unstable PE.

For all three systems, PE (position error) increases as the target object gets closer to the boundary as shown in Fig. 3:*Right*, while electrode plane has little effect on PE (Fig. 3:*Left*. SD (shape deformation) and RNG (ringing) are higher with system C compared to the other two systems, and system A has higher RNG for the target with vertical movement compared to systems B and C.

4 Discussion and Conclusion

This paper describes a stable and accurate test phantom and reproducible procedures used for evaluating the performance of EIT hardware and image reconstruction systems. A reproducible protocol was used to test the performance of three EIT systems.

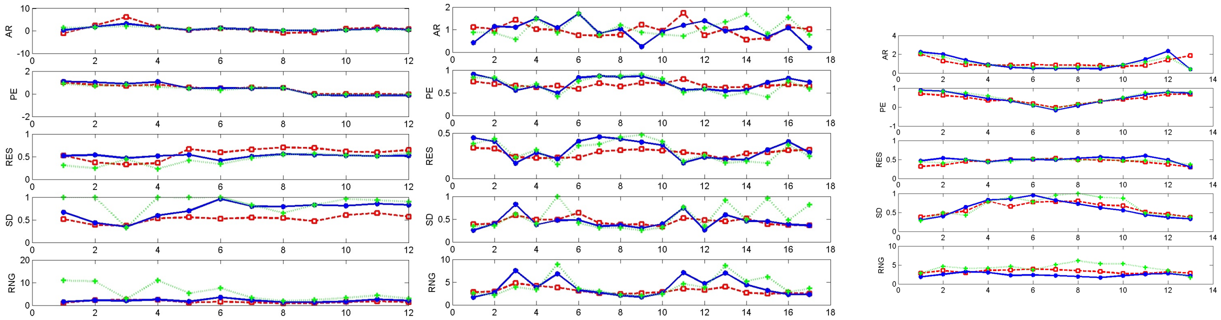

Figure 3: Performance figures of merit for evaluation of GREIT images with *Left:* vertical, *Middle:* circular and *Right:* horizontal movement displacements using systems: *A* (red dashed line with square marker type), *B* (blue solid line with asterisk marker type) and *C* (green dotted line with plus marker type).

These results are somewhat counterintuitive, in that image quality parameters vary between systems, which cannot occur if an EIT system is simply a measure of transfer impedance with some independent noise. We are studying the systems to explain this effect. Typically there is visually little difference in reconstructed images for most target positions with the three EIT systems. Thus, comparisons are carried out based on detectability measure and figures of merit on three EIT systems. The reproducible procedures and test phantoms were found to be effective for evaluating the performance of different EIT hardware and image reconstruction systems in terms of detectability measures. To encourage use of this methodology, all software, robot and phantom construction design details will be made available on www.eidors.org under an open source license.

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