Human Interface Design using Button-type PEDOT Electrode Array in EIT

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Abstract. Animal and human experiments using a multi-channel EIT system requires a cumbersome procedure to attach multiple electrodes. We have to ensure good contact of all electrodes and manage many lead wires during experiments. The problem becomes more severe as we increase the number of electrodes. These may limit the applicability of the imaging method in practice. Noting this technical difficulty, there have been a few trials to design human interface means such as electrode belts, helmets or rings. In this study, we developed an electrode belt for long-term monitoring of human lung ventilation. The belt includes 16 embossed electrodes which make good contact with the skin. The electrode is made by conductive polymer and metallic thread. Soft cushion and wide contact area minimize uncomfortable sensation and reduce contact impedances. The electrodes are attached to an elastic fabric belt at equal spacing. We describe details of its design and fabrication. Using the electrode belt and recently developed multi-frequency EIT system KHU Mark2, we show time-difference chest images of three human subjects during normal breathing cycles.

Keyword : EIT, electrode belt, fabric electrode

1. Introduction

In electrical impedance tomography (EIT), we inject current into an imaging object. Measuring induced voltages on the boundary, we may reconstruct cross-sectional admittivity images of the object. Clinical applications may include lung imaging for ventilation monitoring, stomach emptying, head and cardiac imaging [1].

In most applications of EIT, it is important to attach electrodes quickly and stably. During imaging, we must keep good contact between electrodes and the skin regardless of posture. There have been several trials to develop human interface methods such as electrode belts, helmets or rings depending on intended applications [2]. In this paper, we propose a new design of human interface for EIT imaging.

We are especially targeting the monitoring of human lung ventilation using EIT technique. Though the shape of the human chest is approximately an ellipse, it is quite irregular and varies among subjects. We describe a developed flexible electrode belt of a conductive polymer which is equipped with multiple electrodes. For a long-term monitoring application, we adopted dry electrodes.
2. Method

2.1 Electrode
For wider applications, we avoided using a wet electrode with gel. As a wearable sensor, we used a conductive polymer called PEDOT to fabricate a dry electrode. PEDOT or PEDT is a conducting polymer based on 3,4-ethylenedioxythiophene. Its fiber diameter is less than 700 nm as shown in figure 1.

![Fabric coated PEDOT](image1.png)  ![PEDOT fiber (×50,000 magnification)](image2.png)

**Figure 1.** Fabric material for a button-type dry electrode.

Among different conducting polymers, PEDOT has been widely used in recent years. PEDOT coatings possess high stability over different charge and discharge cycles and can be electro-generated directly on a conductive support such as Pt, Au, glassy carbon, indium tin oxide and so on in organic solvents or in aqueous solution [3,4]. Its advantages are high stability, moderate band gap and low redox potential. Poor solubility will be another advantage when we use it as electrode material. Compared with commercial ECG electrodes, it has a relatively high contact resistance of 100 to 200 Ω.

2.2 Electrode belt
Figure 2 shows a design of electrode belt with its length of 48 cm. When it is stretched, it may reach the maximal length of 96 cm. Sixteen electrodes are arranged along the center line of the elastic band. The gap between adjacent electrodes is 3 cm. When the belt is stretched, the gap can be increased up to 6 cm. We use a pair of hooks to connect both ends so that it encloses the chest. Figure 3(a) is the manufactured electrode belt and (b) shows the button-type PEDOT electrode. In order to easily replace the electrode, we adopted a button structure, which is connected to the band by using an eyelet. Figure 4 shows the dimension of the electrode and belt.

![Electrode belt design](image3.png)

**Figure 2.** Electrode belt design.

![Electrode belt.](image4.png)  ![Button electrode.](image5.png)

**Figure 3.** Belt and electrode.

![Button electrode design.](image6.png)

**Figure 4.** Button electrode design.
3. Results

3.1 Noise test

We measured the noise level of the electrode belt on a TX151 gel phantom. We used our electrode belt as well as commercial Ag-AgCl ECG electrodes (2237, 3M, USA). We measured voltage on each electrode on the gel phantom using a biopotential amplifier (MP35, Biopac Systems, USA). Figure 5 shows plots of measured voltages as a measure of noise levels. The Ag-AgCl ECG electrode has a noise level of 6 $\mu$V$_{PP}$. The electrode belt has a higher noise level of about 16 $\mu$V$_{PP}$.

![Figure 5. Noise measurements using fabric electrode belt and commercial ECG electrode on agar phantom.](image)

Using both electrodes, we injected current and measured induced voltages as usually done in EIT data acquisitions. Figure 6 shows evaluated signal-to-noise ratio (SNR). We found that there is no significant difference between two electrodes in both short-term(1 sec.) and long-term(10 min.) SNRs.

![Figure 6. Comparison of SNRs using the KHU Mark2 EIT system.](image)

(a) Short-term SNR vs. frequency.  
(b) Long-term SNR vs. frequency.

3.2 Phantom experiment

Figure 7 show the TX151 gel phantom. We made 3 different TX151 phantoms. The background gel had 0.1% NaCl while two anomalies in blue and red had 0.02 and 0.5% NaCl, respectively. Figure 8 shows reconstructed time-difference images of the TX151 gel phantom using the electrode belt with sixteen PEDOT button-type electrodes.

![Figure 7. TX151 gel phantom.](image)

![Figure 8. Time-difference images of the TX151 gel phantom.](image)
3.3 Human experiment for pulmonary monitor

Figure 9 is the picture of the flexible electrode belt attached on the human chest. During normal ventilation cycles, we collected boundary current-voltage data sets at 50 kHz operating frequency. Figure 10 shows time-difference images of the chest illustrating effects of lung ventilation.

![Figure 9. Electrode belt around the human chest.](image)

![Figure 10. Time-difference images of the human chest using the electrode belt.](image)

4. Conclusion and discussion

We designed the electrode belt with button-type PEDOT dry electrodes. Though it showed an increased resting noise level compared with commercial Ag-AgCl ECG electrodes, its SNR in EIT data was comparable to that of the commercial electrodes. When we used the electrode belt with the new EIT system KHU Mark2, the overall short-term SNR was acceptable for time-difference imaging. From both phantom and human imaging experiments, we could produce time-difference images without degrading the image quality. We plan to apply the flexible electrode belt to clinical EIT imaging of lung ventilation.

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