**A Gold Sensors Array for Imaging The Real Tissue Phantom in Electrical Impedance Tomography**

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**Abstract.** Surface electrodes in Electrical Impedance Tomography (EIT) phantoms usually reduce the SNR of the boundary potential data due to their design and development errors. A novel gold sensors array with high geometric precision is developed for EIT phantoms to improve the resistivity image quality. Gold thin films are deposited on a flexible FR4 sheet using electro-deposition process to make a sixteen electrode array with electrodes of identical geometry. A real tissue gold electrode phantom is developed with chicken tissue paste and the fat cylinders as the inhomogeneity. Boundary data are collected using a USB based high speed data acquisition system in a LabVIEW platform for different inhomogeneity positions. Resistivity images are reconstructed using EIDORS and compared with identical stainless steel electrode systems. Image contrast parameters are calculated from the resistivity matrix and the reconstructed images are evaluated for both the phantoms. Image contrast and image resolution of resistivity images are improved with gold electrode array.

1. **Introduction**

The design and development errors in the Electrical Impedance Tomography (EIT) [1-2] sensor array attached to the boundary of the EIT phantoms [3-5] usually produces boundary data errors which reduces the signal to noise ratio (SNR) of the boundary potentials. Low SNR of the boundary potential data leads to the errors in reconstruction process providing images with poor quality. Gold electrodes are found suitable for improved image reconstruction of NaCl phantoms in EIT [6]. A gold electrode array with high geometric precision is developed for studying the resistivity imaging of real tissue phantoms in electrical impedance tomography. The layout and required mask of the electrode array containing sixteen identical square electrodes is designed in CADSTAR. The flexible gold electrode array is developed by depositing a gold thin film (2 μm) on a flexible FR4 [7] sheet (acting as a substrate) using electro-deposition process [8]. The gold electrode array is put inside a shallow polypropylene tank and the real tissue phantom is developed with chicken muscle tissue paste and fat tissue. An EIT instrumentation [9] developed with a constant current injector, signal conditioners and a USB based high speed data acquisition system is used for constant current injection and boundary data collection. The constant current injector consists of a sinusoidal signal generator and a voltage controlled current source. Signal conditioner block is developed with two filter circuits: a 50 Hz notch filter circuit and a narrow band pass filter circuit with a center frequency of 50 kHz. 1 mA 50 kHz sinusoidal constant current is injected to the phantom boundary with opposite current.

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injection protocol and the boundary data are collected using the high speed data acquisition system in a LabVIEW platform for different inhomogeneity positions. Resistivity images are reconstructed and compared with identical stainless steel electrode systems. Image contrast parameters are calculated and the images are evaluated for both the phantoms.

2. Materials and Methods

2.1. Sensors development

The flexible gold electrode array is developed by depositing a gold thin film (2 μm) on a flexible FR4 sheet using electro-deposition process [8]. The layout and required mask of the electrode array containing sixteen identical square electrodes (width - 10 mm, height - 10 mm) is designed (Fig. 1a) in CADSTAR software. Copper cladded flexible FR4 sheet (thickness = 200 μm, copper thickness = 35 μm) is chosen as the electrode array substrate (Fig. 1a) and the electrodes patterns are made using UV light lithography. Using photolithography required electrode patterns of the copper layers are made on the FR4 sheet. All the electrode patterns are electroplated with a Ni layer of 2 μm thickness (Fig. 1b) and the Ni patterns are electroplated with 2 μm thick gold layer (Fig. 1b). Ni layer is introduced between Au layer and Cu layer for improving the adhesion. All the gold electrodes (Fig. 1c) are made up of a 39 μm thick composite coating (35 μm Cu + 2 μm Ni + 2 μm Au) on the 200 μm flexible FR4 sheet (Fig. 1c). All the gold electrodes in the gold electrode array are connected with the connecting wires by soldering process (Fig. 1c). A stainless steel electrode array [5] is also developed with sixteen square electrodes identical to the electrodes in the gold array. Sixteen electrodes are cut from a stainless steel sheet (type-304, thickness = 50 μm) and the sixteen identical electrodes are made with equal electrode area (10 mm × 10 mm) and the SS electrodes are connected with crocodile clips [5].

![Figure 1](image). (a) electrode design, (b) electrode array schematic, (c) gold electrodes in the electrode array.

2.2. Phantom development

The performance of the gold electrode array is studied with a real tissue phantom developed with chicken tissues and the results are compared with a similar real tissue phantom containing identical stainless steel electrodes. Two identical phantoms (Fig. 2) are developed with 16 square (10 mm × 10 mm) thin film gold electrodes and stainless steel electrodes respectively and the resistivity imaging is studied with chicken muscle and fat tissues. Chicken muscle tissue paste [5] is poured into the phantom tanks (Fig. 2a-2d) a cylindrical fat tissue (inhomogeneity) of 35 mm diameter is placed in the muscle tissue and the boundary data are collected for different inhomogeneity positions. The height of the bathing medium in the phantom is kept as 10 mm so that an effective electrode area becomes 10 mm ×10 mm. A CME of 25 mm diameter is placed at the phantom center for both the phantoms (Fig. 2). The SS electrode phantom is developed with a stainless steel electrode array (Fig. 2b and 2d) with sixteen square electrodes identical to the electrodes in the gold array. Sixteen identical electrodes with same contact area (10mm × 10 mm) are cut from a stainless steel sheet (type-304, 50 μm thick).
2.3. Data collection and image reconstruction

An EIT instrumentation is developed with a constant current injector [10], signal conditioners, an electrode switching module and data acquisition system for boundary data collection. A USB based high speed data acquisition system is developed with NI USB-6251 DAQ interfaced with LabVIEW software. 1 mA, 50 kHz sinusoidal current signal is injected to the phantom boundary and the surface potentials are collected for all the projections using opposite current injection protocol [11]. Boundary potentials are measured for both the chicken phantoms with different inhomogeneity positions and resistivity images are reconstructed in Electrical Impedance and Diffuse Optical Reconstruction Software (EIDORS) [12]. CNR [13], PCR [13], COC [13] and DRP [13] are studied and the reconstructed images are evaluated for both the phantoms.

3. Results and Discussion

Results show that the contrast and the resolution of the resistivity images of the chicken tissue phantoms are improved with gold sensor array. CNR, PCR and COC of the resistivity images of gold electrode chicken tissue phantom are found more compared to the SS electrode phantom (Table 1). It is observed that the resistivity images obtained from chicken tissue phantom with gold electrode array are less noisy (Fig. 3) compared to the images reconstructed from the identical SS electrode system.

| Parameters | Inhomogeneity at Electrode 3 | Inhomogeneity at Electrode 5 |
|------------|------------------------------|------------------------------|
|            | SS Electrode | Gold Electrode | SS Electrode | Gold Electrode |
| CNR        | 2.31          | 2.78            | 2.28          | 3.55           |
| PCR        | 40.41         | 71.22           | 51.20         | 78.36          |
| COC        | 2.95          | 3.38            | 2.96          | 5.27           |

It is observed that, for SS electrode chicken tissue phantom with fat tissue at electrode number-3, the image blurring encountered in the reconstruction (Fig. 3a) is found more compared to the blurring encountered in the images with gold electrode system (Fig. 3b). DRPs of the images (Fig. 3c) show that the reconstructed resistivity profiles are more acceptable compared for gold electrode system compared to the profiles obtained for SS electrode array. This is because of the high SNR of the gold
electrode system. Similarly it is also observed that, for SS electrode chicken tissue phantom with fat tissue at electrode number-5, resistivity image quality is poor (Fig. 3d) compared to the gold electrode system (Fig. 3e). DRPs of the images (Fig. 3f) with gold electrode chicken tissue phantom show that the reconstructed resistivity profiles are more acceptable compared to SS electrode system.

4. Conclusions
Gold sensors array is developed to improve the resistivity images of real tissue phantoms in EIT. Resistivity images of gold electrode real tissue phantoms are reconstructed in EIDORS and the results are compared with the identical SS electrode systems. Results show that the electrodes performance is improved for the gold electrodes with precise geometries obtained with electrodeposition process. The image quality is improved with gold electrode array compared to the SS electrode systems. Results show that the image contrast and image resolution of resistivity images are improved with gold electrode array compared to the SS electrode system. Results also show that, in gold electrode system, the CNR, PCR, COC and DRP of the reconstructed images are improved. Hence the quality of the boundary data and the images can be improved using a gold electrode array. The entire resistivity imaging studies on real tissue phantoms showed that the gold electrode system improves the resistivity image and hence the gold electrode array can be suitably used for improved EIT image reconstruction.

5. References

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