Exploring Alternative Current Injection Patterns in ERT to Enhance Central Sensitivity: A Multi-Injection Measurement Strategy

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ABSTRACT

Electrical Resistance Tomography (ERT) is a promising imaging technique for industrial applications, yet it suffers from low sensitivity in the central region of the imaging domain, limiting its effectiveness in detecting internal anomalies. To address this challenge, a novel multi-injection strategy is proposed and investigated in this study. Simulation results demonstrate that the new strategy enhances detection capability in the central region compared to conventional approaches. However, the reconstructed images show minimal improvement over the conducting boundary method due to the inherent limitations of the Linear Back Projection (LBP) algorithm, which yields low-resolution outputs. These findings highlight the potential of advanced injection strategies while underscoring the need for improved reconstruction algorithms to fully realize their benefits.

Keywords: ERT, conducting boundary strategy, multi-injection strategy, COMSOL

1. Introduction

ERT, a particular form of electrical impedance tomography (EIT), has gained acceptance as a useful means of rapidly describing the resistivity or conductivity distribution of materials inside a process vessel or pipeline. The sensor geometries required for the process equipment are mostly concentrated on embedding invasive but non-intrusive electrodes into a wall vessel/pipe section. ERT is one of the most extensive modalities of tomography and has considerably evolved since it was invented in the 1980s. It has become a promising technique in monitoring and analysing various industrial flows because of its diverse advantages, which include high speed, low cost, suitability for various sizes of pipes and vessels, no radiation hazard, and non-intrusiveness [1], [2], [3], [4].

For electrical tomography, the adjacent method is the most commonly used form of measurement. The conducting boundary strategy is employed when the column is from conducting material. However, measurement from all existing methods has very low sensitivity in the central region of the pipe wall [4], [5]. A strategy to improve sensitivity remains a key problem in ERT measurement. The central region which corresponds to the deepest area of the region of interest is a key problem in EIT/ ERT measurement. The measurement theory of EIT emphasises that measurement suffers with low sensitivity on the central area. Correspondingly, the image quality in that area is relatively poor [5], [6].

Most injection schemes have only applied a common excitation strategy such as adjacent, opposite, conducting, and so on. Technique to raise the measurement sensitivity and hence improve the image quality in the central area still remains the primary problem in EIT measurement. In recent journal articles, some researchers have proposed the methods to improve the image quality in the central region when using Electrical Resistance Tomography (ERT), especially in pipe or subsurface applications. Chen et al. (2022) has proposed a method that introduces electrodes inside the region of interest (e.g., inside a pipe), significantly improving sensitivity and resolution. To address the issue of central artifacts introduced by this internal excitation, a mixed excitation strategy along with a tailored reconstruction algorithm is employed. Simulation results demonstrate that this new approach significantly enhances image resolution and overall reconstruction quality in the central area[1]. Su et al. (2022) propose a novel inversion technique based on reflection coefficients, which emphasizes boundary contrasts rather than smooth transitions. By incorporating reflection information into the inversion process, the method enhances the detection of resistivity changes, especially in areas with low sensitivity such as the center of pipes or subsurface zones. Simulation results demonstrate that this approach significantly improves the resolution and clarity of central features [2]. However, the technique to raise the measurement sensitivity and hence improve the image quality in the central area still remains the primary problem in EIT measurement applying metal wall vessel/pipe.

In this paper, a new technique called a multi injection strategy is proposed. The method is focused on the application of metal wall vessel. A simulative study was conducted to test the applicability of the technique in solving this issue. The results will be compared to the conducting boundary strategy output.

2. ERT System

ERT has gained acceptance as a useful means of rapidly delineating the resistivity distribution of materials inside a process vessel or pipeline [7], [8], [9]. Most of the primary sensor geometries for the process equipment concentrate on embedding invasive but non-intrusive electrodes into a wall vessel/pipe section composed of an electrically non-conductive material such as acrylic, Perspex, or polyvinylchloride. Conversely, most industrial pipelines and process vessels are constructed from conducting metallic composites. Therefore, in this research, the development and improvement of ERT measurement methods to accommodate this type of environment is proposed.

The ERT system is primarily composed of three units: a sensor/electrode array, a data-acquisition system (DAS), and an image reconstruction system/ host computer, as shown in Figure 1. The electrode array mounted on the vessel generates a rotational electrical field within the region of interest by applying excitation signals, the resultant signals of which are then acquired. The sensor/electrode is used for both excitation and detection. An accurate and stable DAS is a basic necessity for the ERT system. It is responsible for obtaining quantitative data that reveal the state of the conductivity distribution inside the tank. It completes a series of tasks such as excitation signal generation, electrode status control, signal conditioning, and demodulation. This has to be achieved accurately and quickly in order to monitor small changes of conductivity in real time. The acquired data are then sent to the host computer for image reconstruction and information extraction. Using suitable reconstruction algorithms, two- and three-dimensional (2D and 3D) conductivity distribution images are generated from which phase hold-up, flow velocity, and other information can be extracted.

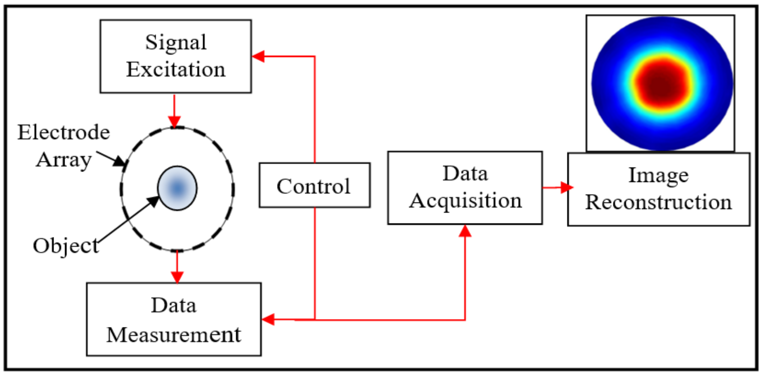


Figure 1. System configuration of ERT

Conducting boundary strategy (CBS) was designed by Wang [10] for the application of electrically conducting boundaries for use on metal pipes/process vessels. The boundary strategy illustrated in Figure 2 uses only two electrodes for each measurement, in contrast with the four electrode measurement strategies described in adjacent stategy, opposite strategy and diagonal/cross method[11], [12]. In CBS, the current is injected from one electrode and the output voltages are measured at the remaining electrodes. The whole conducting boundary herein acts as the current sink, thus resulting in a lower common mode voltage (CMV) across the measurement electrodes. Consequently, neither common mode feedback nor earthed (load) floating measurement are required in this method, unlike other strategies. Furthermore, the metallic or conducting pipe that has been grounded will act as a shield, reducing electromagnetic interference effects. For identically shaped process vessels, the conducting boundary strategy yields lower amplitude of output voltage by a factor of approximately seven, compared with the adjacent strategy.

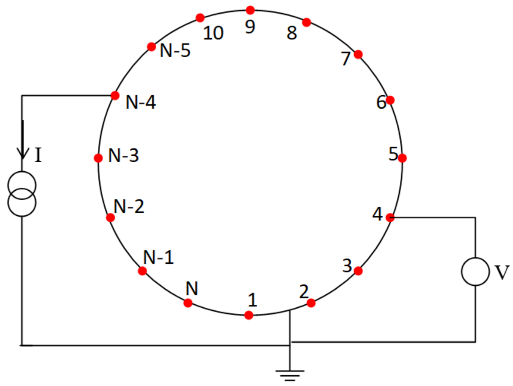


Figure 2. Conducting boundary strategy

3. Methodology

A stronger electric field is required to enhance the measurement sensitivity when the receiving electrode is farther from the source. Thus, this multi-injection strategy was proposed. The proposed technique aimed to enhance measurement sensitivity towards the deep area of the region of interest. It is called a multi injection strategy because different values of current source were injected on the same electrode and only certain pair of electrodes were the receiver electrodes for each of the current values. This is illustrated in Figure 3. Initially, the smallest value of current, for example 5 mA, was the source and the output measurement was taken on the neighbouring electrode. When e1 was set as the excitation electrode, the first measurement was taken on e2 and e16. The current source, which is still injected on e1, was then switched to a higher value, for example 10 mA. The output potentials were then taken concurrently on e3 and e15. The source then switched to 15 mA and the outputs were taken on e4 and e14. For output measurements on e5 and e13, a higher current of 20 mA was injected on e1. Simultaneously, the source was switched to 25 mA and the reading was taken on e6 and e12. Finally, a current value of 30 mA was injected and the output readings taken on electrodes e7 – e11, respectively.

The relevant physics interface was assigned and the boundary and initial conditions that describe the real experimental setup were defined. The *Electric Currents* interface was chosen as this would produce an electrical field and has the electrical potential distribution required for the analysis. It contains the equations, boundary conditions, and current sources for modelling electric currents in conductive media, thus solving the electric potential. To overcome the grounding effect of the vessel, the whole of the conducting vessel behaved as a grounded current sink. The output potentials of the system were obtained from COMSOL simulation and the tomogram was reconstructed using the LBP (non-threshold) technique.

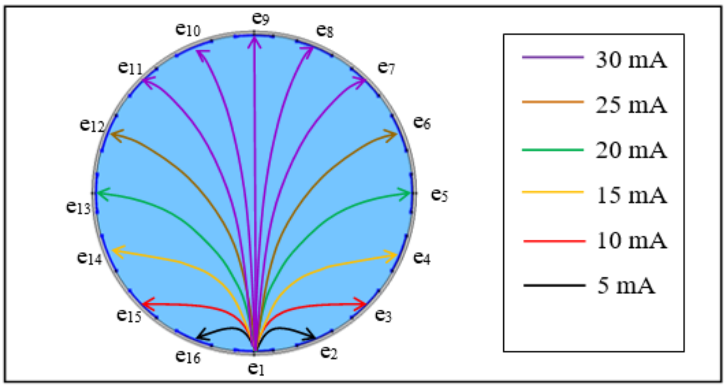
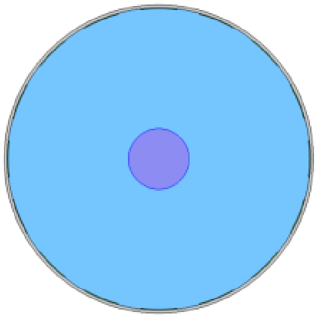
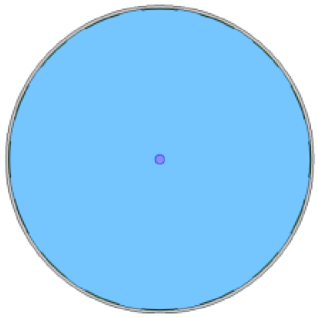


Figure 3. Multi injection strategy

The reconstructed images using the conventional method (conducting boundary strategy) versus the new method were tested to assess the latter's applicability. Two test profiles (gas bubble model) were investigated in COMSOL, each of which had a single bubble with diameters of 20 mm and 3 mm, respectively. The test profiles were placed in the investigation column in a pre-defined position as shown in Table 1, which is at the centre of the region of interest, which was the deepest area in the system.

Table 1. Test profile information

Phantom A (20 mm diameter)		**Phantom B (3 mm diameter)**	

4. Results and Discussion

The output measurement for a conducting boundary strategy using a single current source of 5 mA was then compared with the proposed new injection strategy. The result is presented in Figure 4. The new method demonstrates that the new excitation scheme does improve measurement sensitivity towards the central area. This is observed from the shape of the output potential plot in Figure 4 in which the output potential for the proposed method yields higher output values for electrode positions placed farther from the source electrode.

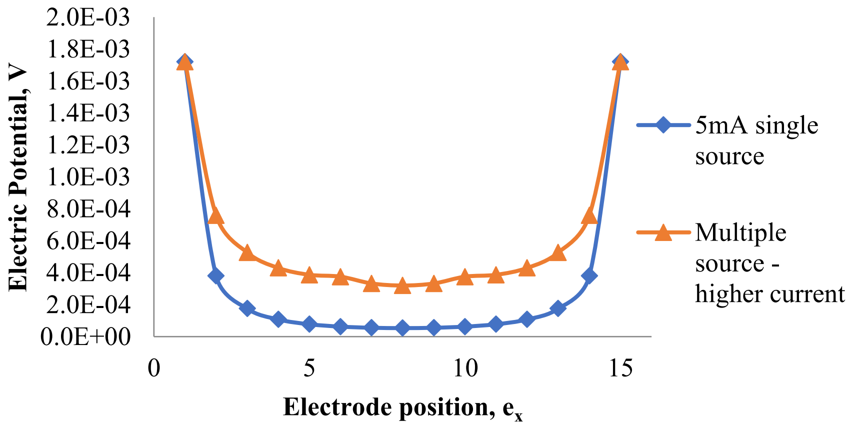
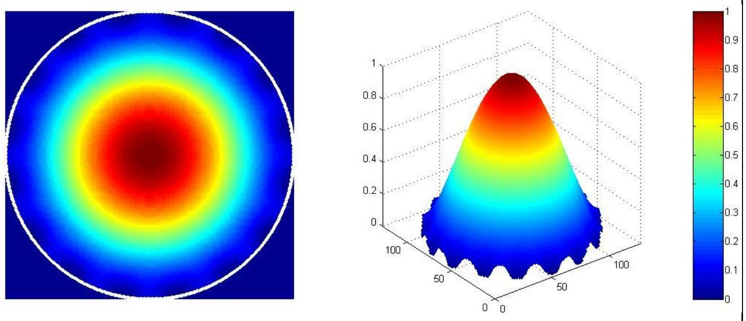
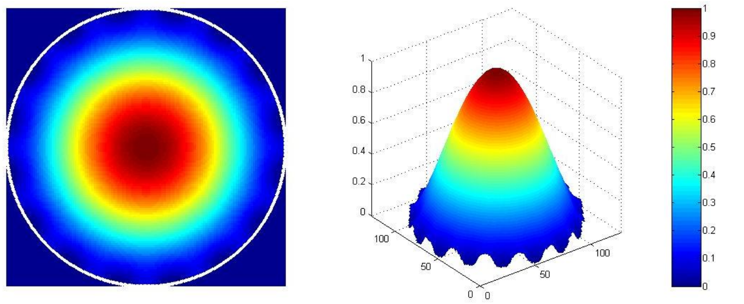
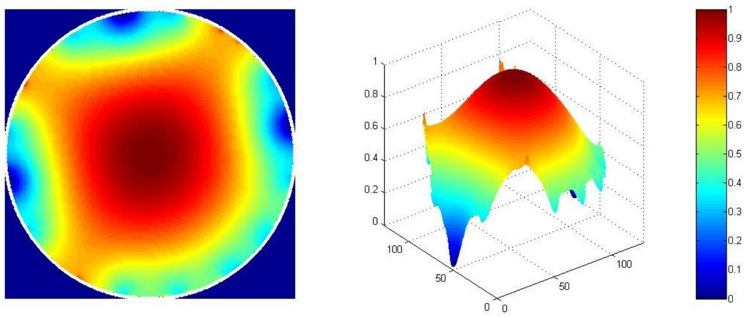
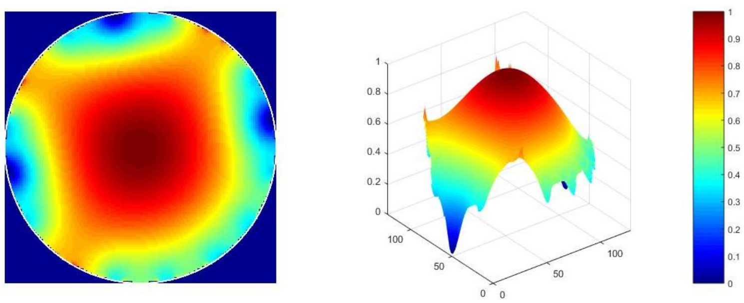


Figure 4. Comparison for output measurement using single and multiple sources

As shown in Figure 4, implementation of the new injection strategy contributed to improving the central region problem in ERT. It allowed the development of new sensitivity distribution and LBP image reconstruction. The applicability of the proposed method was evaluated by comparing reconstructed images obtained using the conventional conducting boundary strategy with those produced by the new approach. COMSOL simulations were conducted on two phantoms, each containing a centrally located bubble with diameters of 20mm and 3mm respectively. The results are presented in Table 2. These show that both strategies yield no difference in the reconstructed image. This does not align with the simulation conducted above. This might be due to the very small difference in sensor loss value for both strategies. Alternatively, it may also be due to the type of algorithm used as it is known that LBP has the disadvantage of producing relatively low-resolution images. The proposed strategy might have a high impact on an ERT system applying a metal pipe wall if the system applying the algorithm provides a better resolution image.

Table 2. Reconstructed image using conducting boundary versus new method for:
(a) Centre bubble with 20 mm diameter,
(b) Centre bubble with 3 mm diameter

(a)	**Reconstructed image using LBP**
Conducting Boundary Strategy	
Multi Injection Strategy	
(b)	**Reconstructed image using LBP**
Conducting Boundary Strategy	
Multi Injection Strategy	

5. Conclusions

A new injection strategy was investigated. The simulation study showed that the new strategy with multi-injection did improve detection of the central region in ERT. However, the reconstructed images for the method showed no difference in image between the proposed strategy and the conducting boundary approach. This is due to the low-resolution image of LBP. The presentation of new injection method has contributed a finding in ERT to improve the central region problem in ERT. From the simulation result, an improvement of its U-shape plot has been presented. A robust thresholding technique or iterative algorithm can be considered to increase the quality and better spatial resolution of the tomogram.

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