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Development of Electrical Resistance Tomography Applying Vertical Metallic Column

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Development of Electrical Resistance Tomography Applying Vertical Metallic Column

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Abstract. Majority of industrial pipelines and process vessels are constructed from conducting composites. This paper focusing on the hardware and software development of laboratory test Electrical Resistance Tomography (ERT) measurement methods to obtain the cross-sectional image of the conductivity distribution of gas bubble phantom in a static vertical metallic column filled with water. The system with sixteen sensors implementation was investigated on a stainless steel vertical column of 100 mm inner diameter. The conducting boundary strategy was applied as the measurement strategy. Software for the current study was developed using Graphical User Interface (GUI) application program in MATLAB. The software contains many functions to ease user to get necessary information from the research done. The cross section image of the bubble phantom was reconstructed using Linear Back Projection (LBP) algorithm after the data collection process was completed. The system has been tested and can successfully generate the phantom under test.

1. Introduction

In recent years, the applications of tomographic techniques as a robust non-invasive tool for direct analysis of the characteristics of multiphase flows have increased. ERT has gained acceptance as a useful means of rapidly delineating the resistivity distribution of materials inside a process vessel or pipeline. The application of ERT for investigating gas holdup distributions in a bubble column is the major subject of much research [1-4]. Most of the primary sensor geometries for the process equipment of ERT concentrated 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, the majority of industrial pipelines and process vessels are constructed from conducting metallic composites. Thereby, the development of ERT measurement methods to accommodate this environment is proposed in this research.

This paper presents the hardware and software development of the ERT system applied to a vertical metallic column. The hardware development covers the design of the column, experimental setup, sensor implementation and preparation, and related circuits implemented throughout the research. It is crucial in proving the developed system can be used to generate the correct tomogram.

2. Development of ERT on Conducting Vessel

The motivation behind the research of ERT on conducting vessel walls was initiated by Wang et al. [5, 6]. By using excitation and measurement strategy and adapting the proposed sensitivity coefficient method, useful images of resistivity distribution are obtained from the metal vessel with insulated electrodes using existing ERT systems. Yuen et al. [7] presented a paper on ERT imaging of a metal-walled solid–liquid filter. Correspondingly, work by Grieve [8] set up an online EIT within pressure filtration for industrial batch processing. The wall was fabricated from an electrically-conducting alloy. Finite element modelling (FEM) was adopted for the system and then it was integrated with a modified version of the electrical impedance tomography and diffuse optical tomography reconstruction software (EIDORS) 3D algorithms to provide a three-dimensional image within the metallic vessel using the complete electrode model.

A novel EIT diagnostic system has been developed and used by Liter et al. [9] to quantitatively measure material distributions in opaque multiphase flow within electrically-conducting (i.e. industrially relevant or metal) vessels. The system applied seven equally spaced ring electrodes to a thin non-conducting rod that was inserted into the vessel. In this work, Sandia's steel pilot-scale bubble column reactor (SBCR) was used as the plant. Only resistive EIT which is the ERT is considered for the purpose of this work. The invasiveness of the electrode used in the system created a non-axisymmetric flow-field disturbance that introduced a bias in the current flow paths. The disturbance was not modelled in the FEM simulations used to reconstruct the electrical conductivity distributions and thus presented a source of possible significant error.

York et al. [10] has progressively published his work on the EIT system within metal-walled industrial production pressure filters for a number of years. The metal wall strategy is employed in the intrinsically safe instrument developed. Sensor architecture has been implemented that is compliant with the process such that it is not detrimental to the efficiency or the integrity of the associated vessel structure. MATLAB-based EIDORS 3D software has been employed to yield images from simulated data.

A 3D image reconstruction using real EIT measurements obtained from a metal-walled (stainless steel) laboratory test platform has been investigated by Davidson [11]. It is considered to be comparable to a large-scale industrial filtration unit. Two image reconstruction techniques have been applied via relatively sophisticated FEM modelling. A generalized Tikhonov regularization method is compared to the linear back projection (LBP) technique. It is observed that the regularized technique is far less sensitive to the modelled geometry compared to LBP. In addition, the regularized technique is more successful in accurately reconstructing multiple inhomogeneities within an aqueous system. A further experiment has shown similar sensitivity in a wetted powder-based system. It is concluded that EIT via a regularization method has significant potential for detecting 3D malformations and non-uniformities in industrial pressure filtration systems.

3. Methodology

In this research, an ERT system had been developed to obtain the cross-sectional image of the conductivity distribution of gas bubble phantom in a static column filled with water. The system was investigated on a stainless-steel column of 100 mm inner diameter. Acrylic pipe was placed on the upper and lower parts of the conducting column so that user can observe the flow pattern within the fabricated column. The PVC holder was attached in between the acrylic and steel pipe to support each other. The 3D design and the dimension in mm of the column is as reveals in Figure 1.

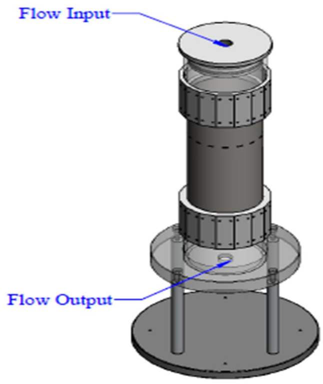

Figure 1. 3D design of the column

Sixteen electrodes were placed equidistantly around the inner periphery of the column such that it made contact with the fluid inside the pipe but did not disturb the flow inside. The conducting boundary approach has been adopted in the experiment where a 5 mA bidirectional pulse current is injected into the system and the output voltages were gathered. The output voltage from the receiving electrode was then amplified in signal conditioning part. The pipe itself acts as a ground. The cross section images of the bubbles were reconstructed using LBP after the data collection process was completed. The experimental setup for this aforementioned ERT system is depicted in Figure 2.

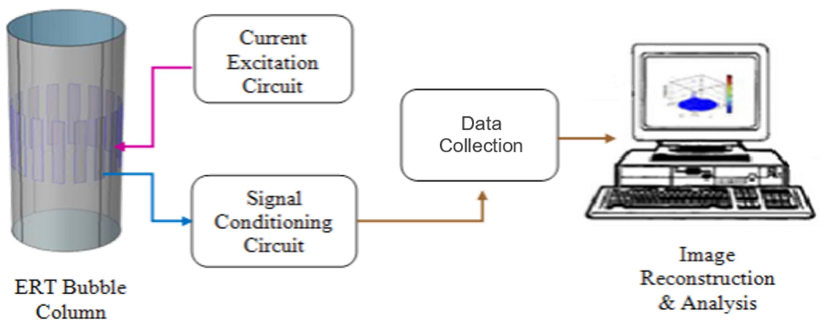

Figure 2. ERT experimental setup

Before selecting suitable electrode to be used in the experiment, several requirements were taken into consideration. First the electrode will be placed inside the inner circumference of the pipe. Second is it must not disturb the flow pattern inside the pipe. Third is that the electrode must be insulated from the metal pipe. And last but not least, it needs to be highly conductive than the fluid inside the pipe for ERT system.
Owing to those needs, it was decided that gold plated flexible PCB with FR4 as the insulating layer will be implemented as the electrode sensor in the experiment. The conductive side of the electrode is the gold coated material. The size of the electrode is 12 mm x 100 mm. The thickness of the PCB is made as thin as possible such that it would not disrupt the flow within the pipe.
The selection of sensor up to its arrangement plays an important role to achieve it. For this experiment, sixteen electrode sensors were placed at equal intervals within the inner surface wall of the conducting, stainless steel column. The inner cross section view for the electrode placement is shown in Figure 3. For the resistivity sensing, the sensors need to be in contact with the flow to obtain the conductivity changes and distribution information within the column.

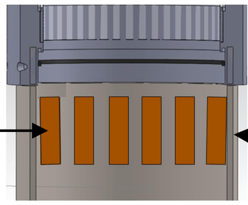

Figure 3 Inner cross section view of the vessel wall

The column is laser cut at sixteen points so that the output pitch of the flexible cable can go through it before being connected to the flexible flat cable (FFC) connector. Rubber fitting along with adhesive silicone glue was used at each inner and outer parts of the positioned electrode to ensure no leakage occur along the experiment when the column is filed with fluid. The insulated part of the electrode was also glued to the wall to guarantee the electrode will stick tightly to it. This is to ensure there will be no bubble formation in between electrode and the column as they could lead to information loss. The arrangement is as shown in Figure 4.

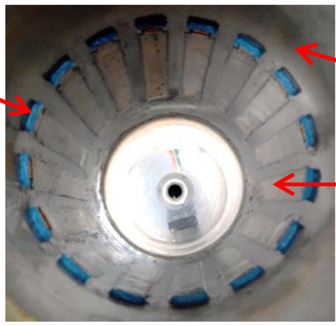

Figure 4. Inner view for the electrode's placement

The output pitch were connected to the FFC connector outside the pipe. It was then connected to the circuit board consisting of the current source and signal conditioning circuits. All required data were collected for post-processing in image reconstruction part. In this research, a bidirectional pulse current source consists of a pulse generator and voltage to current converter was employed. The voltage controlled current source (VCCS) using a monolithic integrated circuit (IC), LT 3092 was adopted in the experiment.

Conventionally, alternating current (AC) signal were applied when dealing with ERT. Thus the demodulation circuit and low pass filter is needed to convert it to direct current (DC) signal before it can be processed in the image reconstruction part. Both just complicate the circuit and deteriorate the performance of the system [12, 13]. In this research, a bidirectional pulse current was used as it is easier to handle than sinusoidal signal and also simplify the circuit. Bidirectional pulse is chosen over constant dc source to eliminate the polarization effects on the electrodes. To generate the pulse, a microcontroller PIC18F4580 has been programmed so that it will produce a pulse waveform with amplitude 5 V_{p-p} and 3.3 kHz frequency.

The pulse was then fed into LT3092 monolithic IC to produce a bidirectional pulse current. LT3092 is a programmable 2-terminal current source that can produce current from 0.5 mA to 200 mA. Typical current source normally is the combination of diode, resistors, and transistors and sometime is combined with op-amps. So does the LT3092. Figure 5 shows the basic configuration of LT3092 as a current source which comprise of the op-amp and transistor. The two resistors, R_{SET} and R_{OUT} will determine the value of output current produced from the chip.

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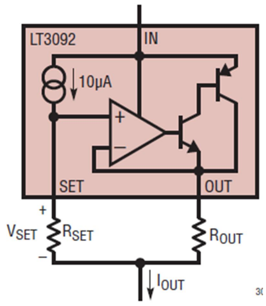


Figure 5. Basic configuration of LT3092

The circuit modification was done using the chip together with the generated pulse to produce a 5 mA bidirectional current pulse. The schematic circuit which generate pulsed current is illustrated in Figure 6. R_{load} represents the conductivity of tap water used in the experiment which is 8.3 x 10^{-3} S/m.

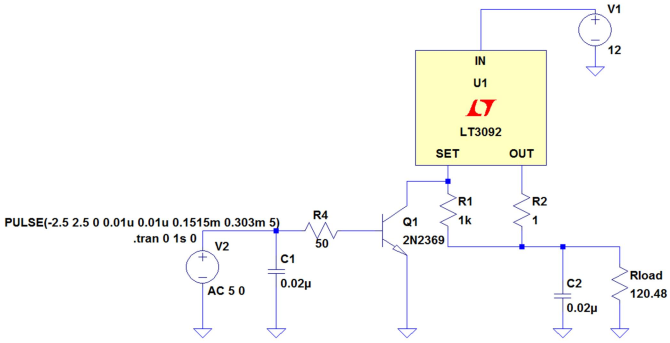


Figure 6. Schematic circuit of the excitation circuit

The voltage signals at the receiving electrodes are very small at mV_{p-p} especially for the receiver that is farthest from the source. Thus, the signals need to be manipulated in a way that it meets the requirement for the next stage processing. Signal conditioning circuit which involve the signal amplification can solve for the problem. The received signals were amplified using a precision instrumentation amplifier, INA114 to yield a better result. The circuit is as shown in Figure 7.

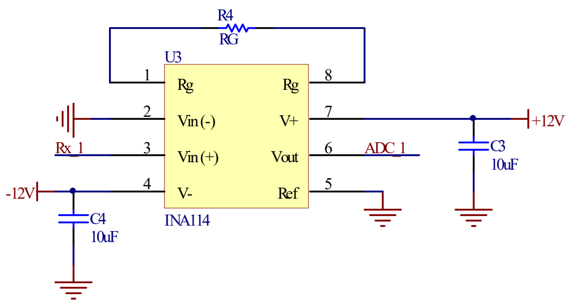


Figure 7. Amplifier circuit

The finalized circuit have been fabricated into a printed circuit board. Sixteen independent boards consisting of the excitation and amplifier circuit each has been placed circularly around the pipe.

Conducting boundary strategy was applied in taking the measurements. The overall setup is shown in Figure 8.

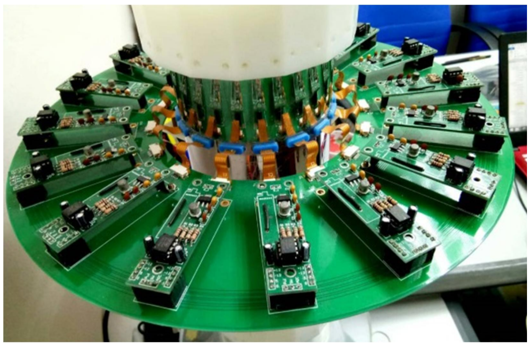


Figure 8. Sixteen independent boards placed circularly around the pipe

The software for the system was developed using Graphical User Interface (GUI) application program in MATLAB. GUI created is as depicted in Figure 9. The animated projection of single pair projection of the sensitivity distribution for conducting boundary strategy along with its weight balance map and normalized sensitivity map can be viewed from the sensitivity distribution dropdown list. The images for the metal column having several phantoms using COMSOL simulation data and via experimental can be viewed just by clicking the construct image button in the GUI. The value for the image quality assessment of the image will be displayed for each phantom selected.

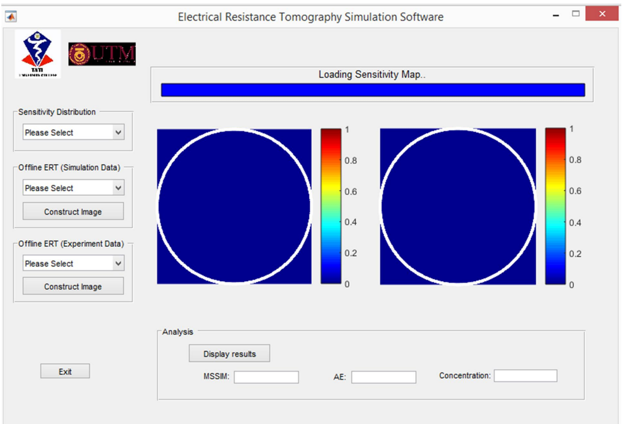
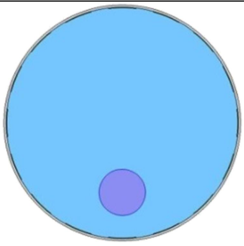
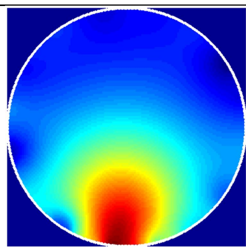
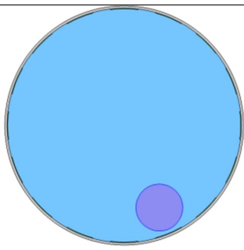
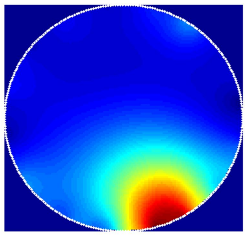
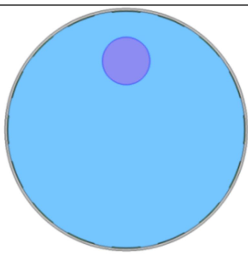
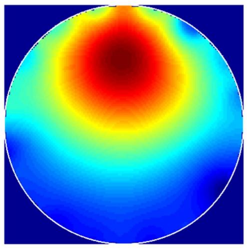
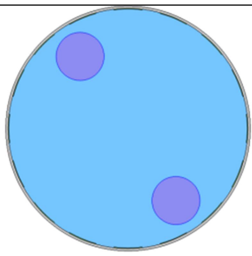
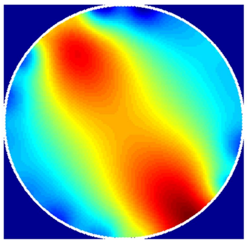
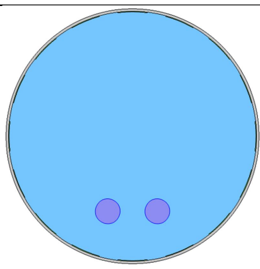
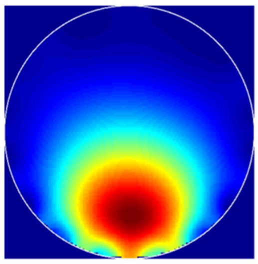
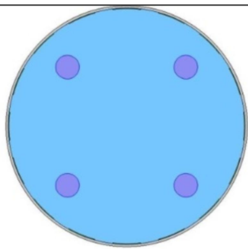
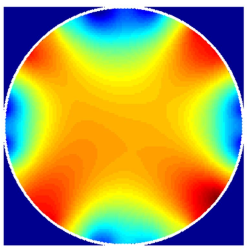


Figure 9. GUI application program

4. Results and Discussion

The reconstructed tomogram for the experiment for each phantom has been tabulated in Table 1. The darkest red region shows the most concentrated region which shows the existence of the bubble phantom. When two near phantoms were located near to each other as in Phantom E, the image does not able to shows the solid existence of two bubble using LBP due to the very dense conductivity distribution there. In overall, the reconstructed images using LBP shows the correct position of the bubble phantom used in the experiments.

Table 1. 2D view of LBP tomograms for experiment

	Phantom	**LBP Image**
Phantom A		
Phantom B		
Phantom C		
Phantom D		
Phantom E		
Phantom F		

5. Conclusion

The developed ERT system has successfully solved the generation of tomograms for liquid-gas two-phase flow regime for the ERT system using metallic column in this research. The locations of the bubbles can also be well distinguished using LBP. However, the exact shape of the bubble was not obtained due to the imperfection of the linear method approximation and blurring effects. As for recommendation, it is suggested to use other algorithm such as iterative or thresholding technique to improve the tomograms.

6. References

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