# Reverse Polarity Scanning Method on 64-Channel Capacitive Sensor to Improve the Performance of ECVT System

**Conference Paper** · September 2018

DOI: 10.1109/ISEMANTIC.2018.8549720



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# Reverse Polarity Scanning Method on 64-Channel Capacitive Sensor to Improve the Performance of ECVT System

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***Abstract*—** This research proposes a scanning method on tomography namely electrical capacitance volume tomography (ECVT). This study discusses the new scanning method of reverse polarity scanning that is applied to 64-channel capacitive sensors. In tomography process, the data acquisition system measures the capacitance from capacitive sensors using scanning process by activating the electrode pairs. Generally, scanning process in ECVT uses conventional scanning by activating an electrode pair and measure the capacitance signal for the pair. This study proposes a new scanning process, by reversing the polarity of electrode in scanning method. The method is applied by changing the polarity of excitation electrode into detection electrode, and vice versa. Then, both of methods are compared to evaluate the performance of the acquisition system. Simulation and experiment are performed using 64-channel capacitive sensors with cylinder rods phantom filled with water. To evaluate the performance of the ECVT system, static objects were used to measure parameters such as Mean Absolute Error (MAE), Coefficient-Correlation (R), and image qualitative observation. From the simulation and experiment, the Coefficient-*Correlation* (R) value as 0.6 and *Mean Absolute Error* (MAE) value as 0.2, so that the proposed method can improve image quality of 3.2%.

***Keywords*—*ECVT; capacitive sensor; reverse polarity scanning; stray capacitance, ill posed.***

## I. INTRODUCTION

Visualization of objects in a vessel based on the measurement of capacitance is called capacitance tomography. The principle of capacitance tomography is by injecting a sinusoidal or square wave signal with a certain frequency to one of the electrode pairs as shown in Fig. 1. As a result, the signal will generates a fringe electric field inside sensor which will affect the object in the sensor [1]. Subsequent, the signal changes are detected by the other electrodes to be measured by the signal detection circuit. Then the signal is processed to be returned to an object using a specific reconstruction algorithm. There are two types of capacitance tomography i.e. ECT (electrical capacitance tomography) and ECVT (electrical capacitance volume tomography). The difference is, the design of sensors in ECT generally use a layer with a maximum number of electrodes 16 pieces. While the design of sensors in ECVT using multiple layers with the number of electrodes more than 24 pieces. The capacitance measurement in the capacitive sensor is carried out directly from the first level electrode to the last level electrode, then the data is reconstructed using a volumetric reconstruction algorithm according to the designed sensor. The result is a volumetric image that corresponds to the original form, and therefore namely ECVT tomography.

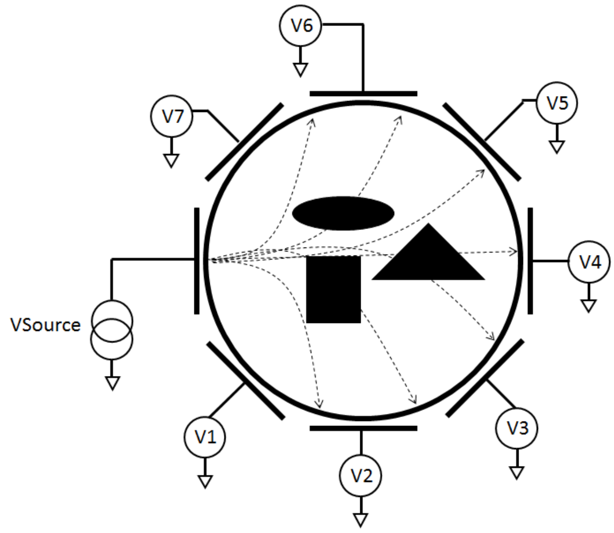


Fig 1. Principle of capacitance tomography

Many ECVT applications are used for multiphase flow [2], [3], gaseous and solid imaging [4]. In recent applications, ECVT has been applied to diagnose abnormalities in biological tissues, such as breast and brain [5]–[7]. The problem often encountered in capacitance tomography is image resolution is still low so that the image reconstruction result is more artifacts. As a consequence, the generated image seems to be directed toward the stronger sites of the sensitivity. Some researchers have been tried to improve the resolution and sensitivity of ECVT measurements, among others by arranging the sensitivity map distribution in capacitive sensors [8], adjusting the electrode configuration [9], and adjusting the electrode rotation [10].

Each electrode arrangement and size are made as accurate as possible by the distance between the electrodes, and the distance between the screen guards is made equal. Screen guard is a shielding made of aluminum or copper foil that connected to ground where its function is to protect the sensor from electromagnetic field interference. However, in the application there are still differences in dimensions of each electrode size and errors in fabrication. In addition, each electrode is connected to one signal generator and one signal detection circuit, so that each electrode has its own characteristics. In the reconstruction algorithm, objects are regarded as non-isotropic which have different values if measured in different directions. Accordingly, the measurement of the capacitance of a pair of electrodes will differ in value if the polarity of electrode pair is reversed.

To overcome the above issue, this research proposed new scanning method that is reverse polarity scanning method. The measurement method is by reversing the polarity of each active electrode by changing the excitation electrode into detection and vice versa. With this method, the amount of measurement data becomes twice as much as the conventional method, thus reducing the main problem in the ill-posed reconstruction algorithm. Ill-posed is the least amount of measurement data when compared to the number of known voxel values causing the inverse S-matrix value unknown.

## II. 64-Channels Capacitive Sensor

In this study designed cylinder-shaped sensor consisting of 64 electrodes with 8 levels, where each level has 8 electrodes as shown in Fig. 2. The sensor has a height of 24 cm, a diameter of 9 cm, a sensor material made from pvc (polyvinyl chloride), and 3x3 cm electrode size. Electrostatic can damage the electronic circuit used to measure capacitance in data acquisition systems. To overcome the problem, each electrode added 1 Mohm resistor which is connected with earth guard [11].

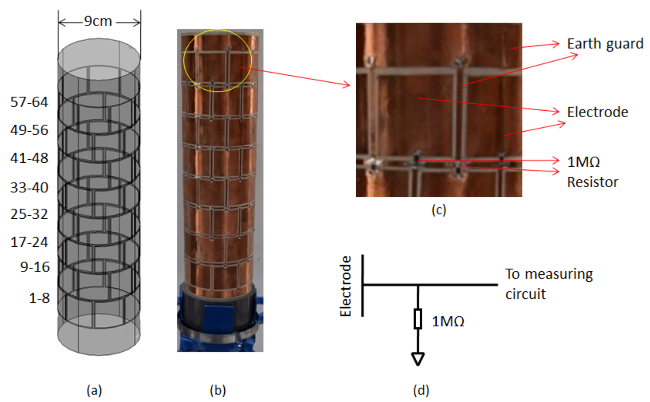


Fig 2. 64-channels cylindrical ECVT sensor; (a) sensor design (b) photograph of the sensor; (c) electrode connection in detail (d) circuit diagram of each electrode

In accordance with the principle of measuring capacitance, two parallel and opposite electrodes will have capacitance values. The value depend on the shape of geometry of the electrode, area of the electrode, distance between the electrodes, and the insulating material (dielectric) between the two electrodes. Analysis of the sensor design shows that between the electrode and the earth guard will give a capacitance value, where in tomography namely stray capacitance. Ideally, the stray capacitance of the sensor can be expressed in Eq. (1) as follows:

$$C_s = NS\frac{\varepsilon_0 \varepsilon_r A}{d} \quad (1)$$

Where, $C_s$ is stray capacitance in the sensor, $N$ is number of electrodes, $S$ is number of sides in a single electrode, $\varepsilon_0$ is dielectric constant in a vacuum of 8.85 $pFm^{-1}$, $\varepsilon_r$ is the relative permittivity of the dielectric material, $A$ is area of electrode, and $d$ is the distance among electrode and earth guard. If the parameters mentioned above are fed to Eq. (1), the stray capacitance of the sensor is 0.0177 pF for one electrode and 4.53 pF for 64 electrodes.

## III. ECVT Scanning Method

Scanning is a way of obtaining data from the capacitive sensor, where the number of data depends on the number of electrodes and the scanning method. There are several methods in the ECVT scan, such as conventional scanning which is a common method. Another method is to arrange the electrode configuration, which combines two electrodes into one excitation and detection electrode [9], and rotary electrode [10]. In this study described conventional multistage scanning applied to the 64-channel ECVT systems.

### *A. Conventional Scanning Method*

Generally the scanning method used in the ECVT system is conventional method, viz. activating electrode pair and measure the capacitance signal, hence the amount of data can be known by Eq. (2).

$$N = n(n-1)/2 \quad (2)$$

Where, $N$ is number of capacitance data, $n$ is number of electrode. For example, the sensor has 8 electrodes then the total capacitance data is 28 data. The conventional scanning process is shown in Fig. 3 through 5. In this example, the number of electrodes is determined by 8 pieces to simplify the explanation. The electrode is marked in different color, the red color is excitation electrode while the green color is detection electrode. There are seven scanning processes that start from the first excitation electrode and end with the seventh excitation electrode.

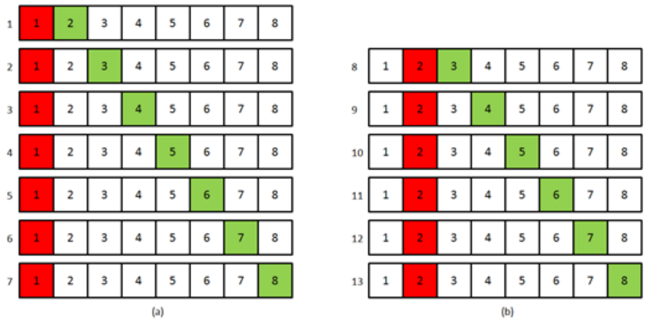


Fig 3. ECVT conventional scanning method; (a) excitation electrode number 1; (b) excitation electrode number 2

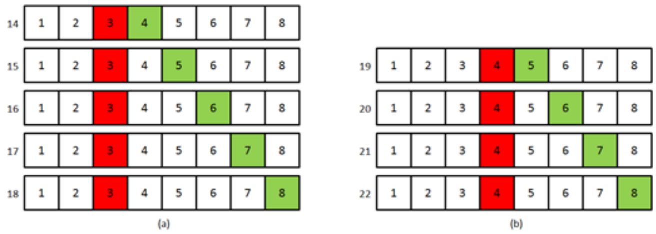


Fig 4. ECVT conventional scanning method; (a) excitation electrode number 3; (b) excitation electrode number 4

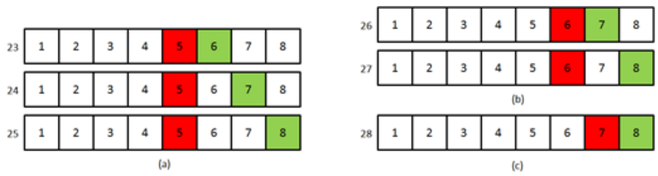


Fig 5. ECVT conventional scanning method; (a) excitation electrode number 5; (b) excitation electrode number 5; (c) excitation electrode number 7

The scanning process starts from the excitation electrode of number 1 and detection electrode number 2 to obtain the first data, the next scan for detection electrode number 3 to obtain the second data, and so on until the eighth detection electrode to obtain the seventh data. After the final detection electrode is scanned, the scan proceeds by activating the second excitation electrode and the third detection electrode to obtain the eighth data, and so on up to the eighth electrode and thirteen data is obtained. After the final detection electrode is scanned, the scan is continued with the next excitation electrode, so on until all electrodes are scanned with the result of 28 data. Table 1 describes the data acquisition of the scanning process in the ECVT system.

TABLE I. DATA ACQUISITION OF THE SCANNING PROCESS

| Excitation Electrode \ Detection Electrode | 1 | 2 | 3 | 4 | 5 | n |
|---|---|---|---|---|---|---|
| 1 | - | $C_{1,2}$ | $C_{1,3}$ | $C_{1,4}$ | $C_{1,5}$ | $C_{1,n}$ |
| 2 | - | - | $C_{2,3}$ | $C_{2,4}$ | $C_{2,5}$ | $C_{2,n}$ |
| 3 | - | - | - | $C_{3,4}$ | $C_{3,5}$ | $C_{3,n}$ |
| 4 | - | - | - | - | $C_{4,5}$ | $C_{4,n}$ |
| 5 | - | - | - | - | - | $C_{5,n}$ |
| n | - | - | - | - | - | - |

According to the Table 1, for example the number of electrodes is known to be 8 pieces, the capacitance readings are obtained from electrode pairs 1-2, 1-3, .., 1-8, 2-3, 2-4, .., 2-8, 3 -4, 3-5, 3-6, .., 3-8, and so on until the pair of 7-8 electrodes. If there are a number of $n$ electrode, then the data acquisition of the capacitance corresponds to Eq. (1).

### *B. Reverse Polarity Scanning Method*

The scanning method proposed in this study is reverse polarity scanning method. The scanning method is essentially similar to conventional scanning, except the measurement of an active electrode pair is taken twice. The method of measurement is by reversing the polarity of each active electrode i.e. changing the excitation electrode into detection and vice versa. Thus the acquisition of the capacitance data can be known by Eq. (3).

$$N = n(n-1) \tag{3}$$

Where $N$ is number of data measurement, $n$ is number of electrode. For example, the sensor with the number of electrodes of 8 pieces, then the total data measurement is 56. Fig. 6 to Fig. 9 describes the scanning process using reverse polarity scanning method. In the picture, given an example of 8 pieces of electrodes to facilitate the explanation. As an illustration, the excitation electrode is colored red while the detection electrode is colored green. There are eight scanning processes starting from the first excitation electrode and ending with the eighth excitation electrode.

In the first process the excitation electrode number 1 and the number 2 are activated to obtain the first data, then the scanning goes up to the detection electrode number 3 and so on until the detection electrode number 8, hence one scanning process are completed and 7 data are obtained. The next process for the 2nd excitation electrode is activated, then the detection electrode is activated starting from electrode number 1, electrode number 3, electrode number 4, and so on until the number 8 electrode to obtain 7 data. The next process for the excitation electrode number 3 is activated and the detection electrode is activated starting from electrode number 1, electrode number 2, electrode number 4, and so on up to the number 8 electrode to obtain 7 data. The process is repeated until the eighth excitation electrode, so that the overall data acquisition of 56 capacitance data are obtained. The difference with conventional scanning is on conventional scanning, in one active excitation electrode the data is only taken once on the next electrode. While in the reverse polarity scanning method, in one active excitation electrode the data is taken twice for the previous electrode and the subsequent electrode.

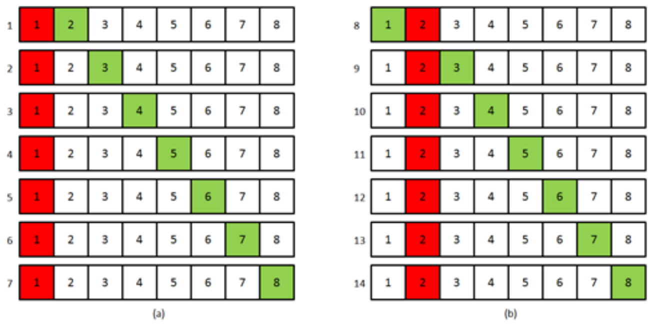

Fig 6. ECVT reverse polarity scanning method; (a) excitation electrode number 1; (b) excitation electrode number 2

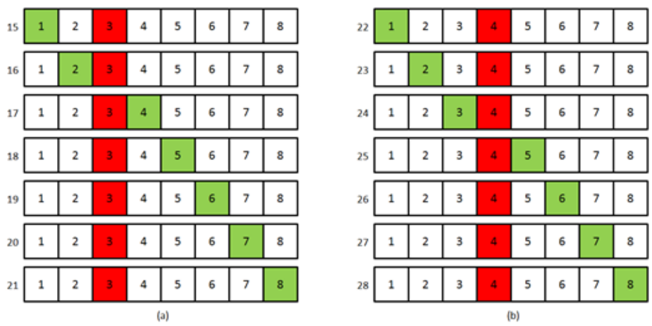

Fig 7. ECVT reverse polarity scanning method; (a) excitation electrode number 3; (b) excitation electrode number 4

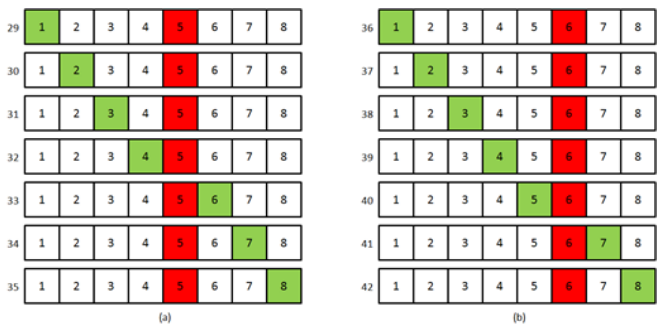

Fig 8. ECVT reverse polarity scanning method; (a) excitation electrode number 5; (b) excitation electrode number 6

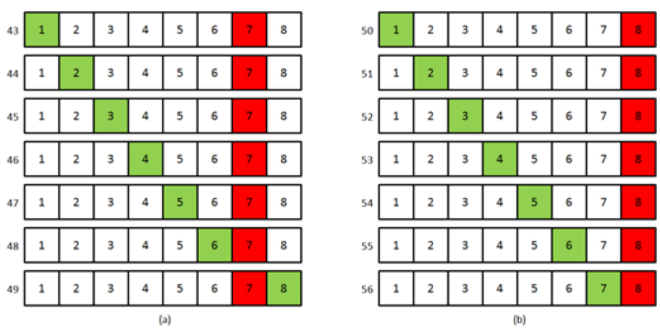

Fig 9. ECVT reverse polarity scanning method; (a) excitation electrode number 7; (b) excitation electrode number 8

The data acquisition of the reverse polarity scanning method is shown in Table 2. For example the number of electrodes of 8 pieces then the readings of the capacitance by the reverse polarity scanning method are obtained from electrode pair 1-2, 1-3, .., 1-8, 2-3, 2 -4, .., 2-24, 3-4, 3-5, 3-6, .., 3-8, and so on up to 7-8. Then the readings are repeated for different polarities i.e. 2-1, 3-1, ..., 8-1, 3-2, 4-2, ..., 8-2, 4-3, 5-3, 6-3, ..., 8-3, and so on up to 8-7. If there are electrodes of a number of n pieces then the acquisition of capacitance data is in accordance with Eq. 3 above.

TABLE II. DATA ACQUISITION OF THE SCANNING PROCESS

| Detection Electrode / Excitation Electrode | 1 | 2 | 3 | 4 | 5 | n |
|---|---|---|---|---|---|---|
| 1 | - | $C_{1,2}$ | $C_{1,3}$ | $C_{1,4}$ | $C_{1,5}$ | $C_{1,n}$ |
| 2 | $C_{2,1}$ | - | $C_{2,3}$ | $C_{2,4}$ | $C_{2,5}$ | $C_{2,n}$ |
| 3 | $C_{3,1}$ | $C_{3,2}$ | - | $C_{3,4}$ | $C_{3,5}$ | $C_{3,n}$ |
| 4 | $C_{4,1}$ | $C_{4,2}$ | $C_{4,3}$ | - | $C_{4,5}$ | $C_{4,n}$ |
| 5 | $C_{5,1}$ | $C_{5,2}$ | $C_{5,3}$ | $C_{5,4}$ | - | $C_{5,n}$ |
| n | $C_{n,1}$ | $C_{n,2}$ | $C_{n,3}$ | $C_{n,4}$ | $C_{n,5}$ | - |

## IV. RESULTS AND ANALISYS

The ECVT sensor scanning process produces capacitance data which is one scanning group by the first 24 electrodes will generate 276 data for conventional scanning method and 552 data for reverse polarity scanning method. The process is repeated up to six times to obtain data as much as 6 × 276 data and 6 × 552 data. The capacitance data is still mixed with the value of stray capacitance whose value varies. In order to be processed and reconstructed into images, the data needs to be normalized using Eq. (4).

$$nc = \frac{C_r - C_l}{C_l} \quad (4)$$

Where $nc$ is the normalized capacitance, $C_r$ is the capacitance to be measured inside sensor, $C_l$ is capacitance at the initial measurement where the sensor has not been filled with the object.

The signal shown in Fig. 7 (a) is the capacitance data of object's by the conventional scanning method of a 64-channel capacitive senor for the first group. The signal pattern is shows the object being scanned appears. The unit of capacitance is expressed in Pico farad. The opposite pair of electrodes will have a low capacitance value, about 0.15pF, while the adjacent electrode pair has a high capacitance value, about 1.5pF as shown in the graph.

The normalization capacitance by conventional scanning method is shown in Fig. 7 (b) where the data is used in image reconstruction. The X axis is the number of data measurement, whereas the Y axis is the normalized value in which the maximum value is 1. The normalization value represents the value representing the permittivity distribution in the sensor. The smaller value means lower permittivity and vice versa.

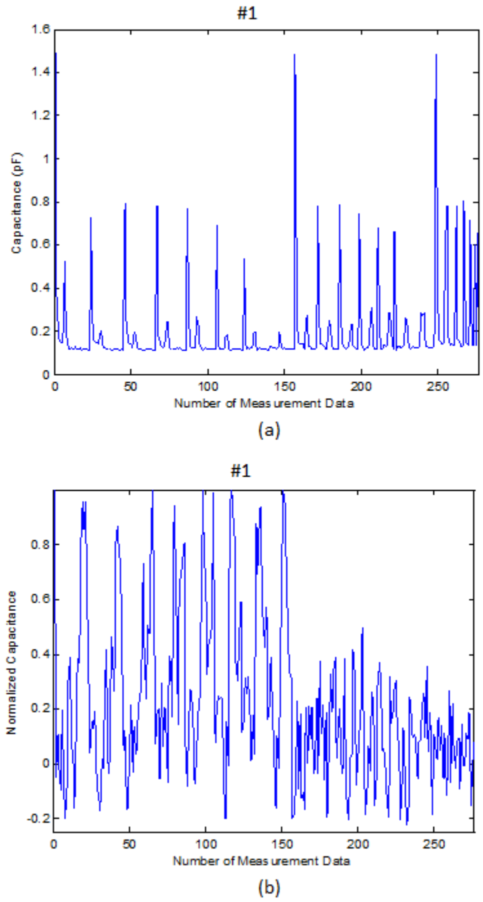


Fig 10. The signal using conventional scanning method from 64-channel capacitive sensor for first group; (a) Capacitance signal; (b) Normalized capacitance

The signal shown in Fig. 8 (a) is a capacitance data by a reverse polarity scanning method from a 64-channel capacitive sensor for the first group. The amount of data is 552 pieces in which the data is twice as much as the conventional method. The normalization graph is shown in Fig. 8 (b) where the data is used in image reconstruction. The X axis is the number of measurement data, whereas the Y-axis is the normalized value whose maximum value is 1.

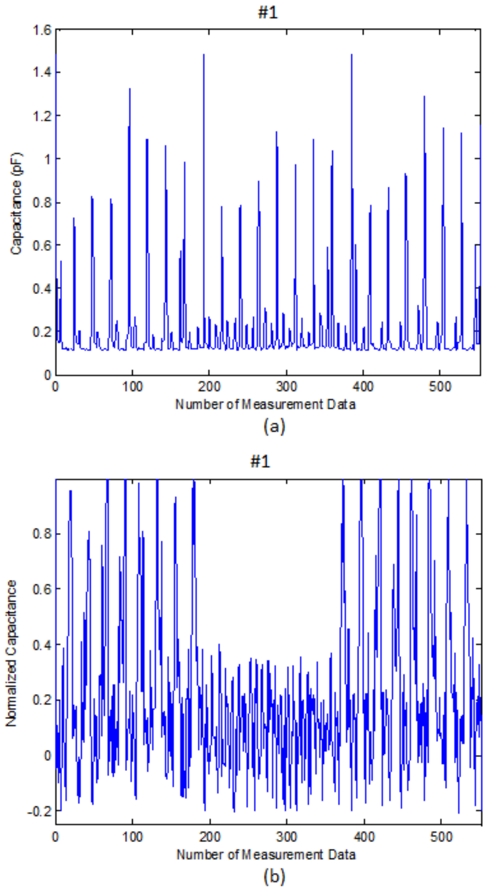


Fig 11. The signal using reverse polarity scanning method from 64-channel capacitive sensor for first group; (a) Capacitance signal; (b) Normalized capacitance

Simulations and experiments have been conducted to determine the performance of the developed ECVT system. The simulation is done using an electromagnetic engineering software to create objects and calculate the matrix sensitivity value. While experiments were performed using an object made of a pvc pipe filled with water ($\varepsilon r = 80$). In image reconstruction used ILBP algorithm. To evaluate the performance of the ECVT system, static objects were used to measure parameters such as Mean Absolute Error (MAE), Coefficient-Correlation (R), and image qualitative observation as expressed in Eq. (5) and (6).

$$MAE = \frac{\sum_{i=1}^{n} |y_i - x_i|}{n} \quad (5)$$

$$R = \frac{n\sum xy - (\sum x)(\sum y)}{\sqrt{n(\sum x^2) - (\sum x)^2}\sqrt{n(\sum y^2) - (\sum y)^2}} \quad (6)$$

Fig. 9 shows the results of image reconstruction for a cylindrical rod object with a combined diameter of 6 cm and 4 cm. Visually shows that the image results by using the reverse polarity scanning method gives better results than using conventional scanning methods. Each image is divided into three parts consisting of the original image used as a comparator, conventional scan image and reverse polarity image. And also each image consists of two images as three-dimensional images and two-dimensional images in a vertical slicing.

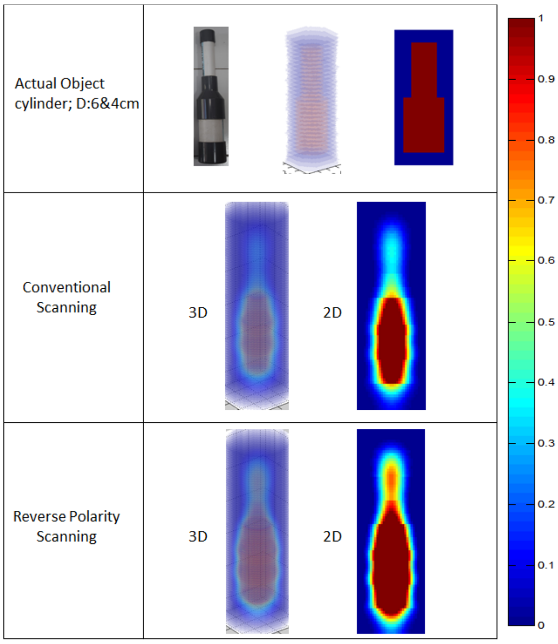


Fig 12. Image reconstruction of cylinder object using conventional and reverse polarity scanning method

Visually shows that the resulting image of all scanned objects is similar to the actual image and also shows that the image produced at the top and bottom ends is slightly convex and pulled up and down. This is due to the characteristic of ILBP algorithm that has elongation error on high contrast dielectrics and if two adjacent objects will have a high error [12]. According to the quantitative measurements, the images generated by reverse polarity scanning method resulting a better image than the conventional scanning method.

TABLE III. QUANTITATIVE PERFORMANCE MEASUREMENT

| Scanning Method | Mean Absolute Error (MAE) | Coefficient Correlation (R) |
|---|---|---|
| Conventional | 0.2281 | 0.6439 |
| Reverse Polarity | 0.2009 | 0.6645 |

From the simulation and the experiments can be calculated percentage comparison between the two methods of scanning. The results show that the reverse polarity scanning method gives better reconstruction results with an average correlation coefficient (R) of 3.2% when compared with conventional scanning methods. By reverse polarity scanning method can also reduce error with MAE value of 10.3% when compared with conventional method.

It has been described in the imaging process, image reconstruction is generally done in under sampling measurement i.e. the measurement data is much less than the matrix sensitivity data [13]. This led to the emergence of many artifacts at some point of the sensor. This problem poses a challenge to the development of scanning methods in the ECVT tomography system. Apart from the limitations in the ECVT reconstruction system that still need to be developed, this deficiency promises to be further developed, by improving the design of electrodes and sensors, improving the signal conditioning circuit in order to measure smaller signals, and applying other image reconstruction algorithms such as NN-MOIRT (Neural Network Multi-criteria Optimization Image Reconstruction Technique) [14], [15].

## V. Conclusion

The design of 64-channel capacitive sensor using new scanning methods on the ECVT tomographic data acquisition system has been tested for qualitative and quantitative performance. The sensor design is useful for multi-phase flow experiments that require long experimental vessel like this design. The experiment is done by comparing conventional scanning methods and reverse polarity scanning method. Simulations and experiments show in general the proposed reverse polarity scanning method provides better reconstructed imagery. From the simulation and experiment result, the average value of Coefficient-Correlation (R) equal to 0.6 and Mean Absolute Error (MAE) is 0.2, so the proposed method can improve the image quality by 3.2%. The advantage of the method is it can increase the amount of measurement data twice than the conventional method so that it can reduce the main problem in the reconstruction algorithm, namely ill-posed. However, this method also increases data acquisition times twice as long as conventional methods. Where conventional scanning methods require acquisition time of 1.52s. Whereas for polarity scanning, exchanging requires acquisition time of 3.03s.

## Acknowledgment

The author would like to thank all parties who kindly contribute to this research: Warsito P. Taruno, and Wahyu Widada from CTECH Labs Edwar Technology. This work is supported by a grant from Hibah PITTA DRPM Universitas Indonesia Grant Number: 2362/UN2.R3.1/HKP.05.00/2018.

## References

[1] D. Sudiana, A. S. Tamsir, and H. Sudibyo, “A digital signal processing algorithm on read out circuit for electrical capacitance tomography,” in *Region 10 Conference (TENCON), 2016 IEEE*, 2016, pp. 1166–1170.

[2] J. M. Weber, K. J. Layfield, D. T. Van Essendelft, and J. S. Mei, “Fluid bed characterization using Electrical

Capacitance Volume Tomography (ECVT), compared to CPFD Software's Barracuda," *Powder Technol.*, vol. 250, pp. 138–146, 2013.
[3] W. Warsito, Q. Marashdeh, and L. S. Fan, "Real Time Volumetric Imaging of Multiphase Flows Using Electrical Capacitance Volume-Tomography (ECVT)," in *Congress on Industrial Process Tomography*, 2007.
[4] A. Wang, Q. Marashdeh, and L. Fan, "ECVT imaging of 3D spiral bubble plume structures in gas□liquid bubble columns," *Can. J. Chem. Eng.*, vol. 92, no. 12, pp. 2078–2087, 2014.
[5] W. P. Taruno *et al.*, "A novel sensor design for breast cancer scanner based on electrical capacitance volume tomography (ECVT)," in *Sensors, 2012 IEEE*, 2012, pp. 1–4.
[6] W. P. Taruno *et al.*, "Brain tumor detection using electrical capacitance volume tomography (ECVT)," in *Neural Engineering (NER), 2013 6th International IEEE/EMBS Conference on*, 2013, pp. 743–746.
[7] W. P. Taruno *et al.*, "Comparisons of Electrical Capacitance Volume Tomography and Ultrasonography for Breast Cancer Detection," *Adv. Sci. Eng. Med.*, vol. 6, no. 8, pp. 845–848, 2014.
[8] Q. M. Marashdeh, F. L. Teixeira, and L.-S. Fan, "Adaptive electrical capacitance volume tomography," *IEEE Sens. J.*, vol. 14, no. 4, pp. 1253–1259, 2014.
[9] Q. M. Marashdeh, Z. Zeeshan, B. Gurlek, and F. L. Teixeira, "AECVT sensors with reconfigurable capabilities for industrial imaging applications," in *Antennas and Propagation (APSURSI), 2016 IEEE International Symposium on*, 2016, pp. 1997–1998.
[10] A. Saputra, W. Widada, and W. P. Taruno, "Rotary sensor system for imaging improvement in electrical capacitance volume tomography," in *Information Technology and Electrical Engineering (ICITEE), 2016 8th International Conference on*, 2016, pp. 1–5.
[11] W. Yang, "Design of electrical capacitance tomography sensors," *Meas. Sci. Technol.*, vol. 21, no. 4, p. 42001, 2010.
[12] W. Warsito, Q. Marashdeh, and L.-S. Fan, "Electrical capacitance volume tomography," *IEEE Sens. J.*, vol. 7, no. 4, pp. 525–535, 2007.
[13] S. Ravishankar and Y. Bresler, "MR image reconstruction from highly undersampled k-space data by dictionary learning," *IEEE Trans. Med. Imaging*, vol. 30, no. 5, pp. 1028–1041, 2011.
[14] Q. Marashdeh, L.-S. Fan, B. Du, and W. Warsito, "Electrical Capacitance Tomography− A Perspective," *Ind. Eng. Chem. Res.*, vol. 47, no. 10, pp. 3708–3719, 2008.
[15] L.-S. Fan, W. Warsito, and B. Du, "Electrical capacitance tomography imaging of gas-solid and gas-liquid-solid fluidized bed systems," *J. Vis.*, vol. 7, no. 1, p. 5, 2004.