Does Parallel Projection is Suitable in Electrical Capacitance Tomography? –A Comparison with Common Approach

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ABSTRACT

Electrical Capacitance Tomography (ECT) is one of the soft field tomography that widely used for the purpose of measurement and monitoring of multiphase flow. Common problem of the soft field tomography is low quality and unstable images in the pipe especially at the center section of the pipe. In this paper, an ECT system with a comparison between common approach and a parallel approach is presented. Simulation in 2 dimensions with 16-electrode is carried out to observe a potential projection. The COMSOL Multiphysics software is used to investigate the state and response of the electric field with this approach by exporting data with 128x128 pixels. Air bubbles as a phantom in the oil medium have been tested and analyzed. Linear Back-Projection Algorithm (LBP) is implemented using MATLAB software to obtain a tomogram. A Multi Scale Structural Similarity, MSSIM was applied to compare both approaches. Consequently, the resolution and quality of the pictures in the pipes can be distinguished. However, a further investigation is needed to improve the parallel approach for ECT system.

Keywords: ECT, Fan projection, Parallel projection

1. Introduction

Tomography is derived from the Greek word 'Tomos' which means section and 'graphy' means photo [1]. In other word, tomography can be used to reconstruct the image within the sensing zone of the interest of the specimen. Tomography has been generally used in medical applications for years. In other word, tomography can be used to reconstruct the image within the sensing zone of the interest of the specimen. ECT system aims non-intrusively to visualize the permittivity distribution inside a sensing area of interest through external boundary capacitance measurements. This technique has been depth studied for industrial process imaging applications. The ECT system produces a tomogram as a result that indicate the system. The tomogram in ECT is based on a variation of permittivity due to a different material distribution [2]. Commonly, the ECT technology uses 8, 12 and 16 electrodes depend on its application [3]. Images can be reconstructed based on the receiving signals and appropriate algorithm.

There are two types of tomography which are hard field tomography and soft field tomography. Hard field tomography consists of transmitting signal that follows a straight–line pattern such as X-ray tomography. Moreover, the hard field tomography has been widely used in the medical field; however, the cost of such equipment is generally very high, and most of the traditional imaging systems contain radioactive sources, which may cause side effects in a patient, especially under long-term exposure [4]. One examples of soft-field tomography is electrical capacitance tomography (ECT). The problem of common approach of an ECT system is low and unstable quality of image at area in the pipe [5]. Also, the sensor field is sensitive to the component parameters distribution, both inside and outside the measurement volume [6]. For this study, Linear Back Projection (LBP) algorithm as in Ref. [7] is implemented. The paper aims to investigate the performance of parallel projection if compared to the common projection in ECT.

2. Principle of ECT

As a condenser, any two adjacent conductors and a single one can be considered. Dielectric properties between the conductors can produce various values of the capacitor [8]. An ECT system is capable of collecting information on the ECT system. The calculation of changes in the flowing material's dielectric properties need to be obtained.

The choice of the number of electrodes around the circumference of the sensor is a trade-off between axial length and radial length. As the number of electrodes increases, the electrode surface area per unit axial length decreases and the inter-electrode capacitances also decrease. When the smallest of these capacitances (for opposite electrodes), reaches the lowest value that can be measured reliably by the capacitance circuitry, the number of electrodes, and hence the image resolution, can only be increased further by increasing the axial lengths of the electrodes [9]. Typically, ECT system consists of a sensor built up of 6, 12 or 16 electrodes in capacitance measurement circuit [6] [10]. In ECT process 6 of electrodes are usually used in visual combustion flame in engine cylinder, 8 electrodes are used for imaging wet gas separator, 12 electrodes are used in measuring three component flow which are gas, oil and water, while 16 electrodes are used in the process of imaging nylon polymerization [1] [11]. Figure 1, illustrates an ECT system where the ECT sensor consists of sixteen electrodes mounted equidistantly along the periphery of an insulated pipe vessel.

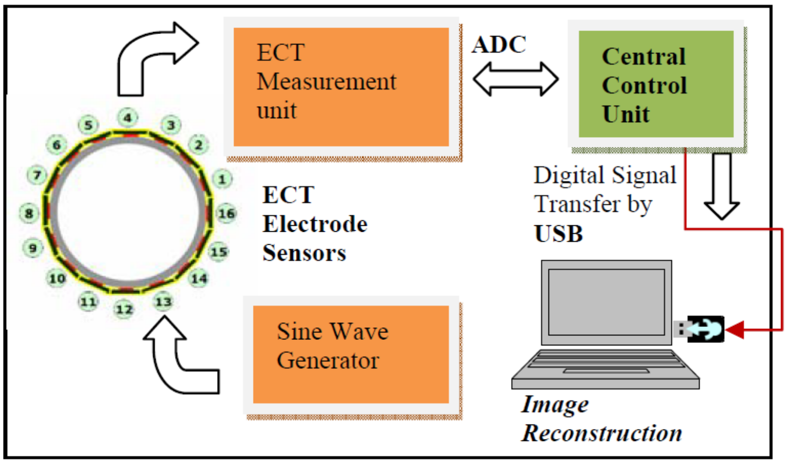


Figure. 1. ECT system topology [10]

Mathematical equation of ECT system is based on the electrostatic field. The relationship between the spatial distribution of the permittivity and the measured capacitances [12], that can be derived from Maxwell's equation as in Equation 1. Gauss' Law expresses the dielectric flux density, D.

$$\nabla \cdot D = \rho v \tag{1}$$

The ρv stands for the volume charge density, while ∇ is the divergence operator. In ECT system, only one electrode is excited at a time and the rest of electrodes will be receiver, this total electric flux over all the electrode surfaces can be calculated as zero, thus the volume charge density is also zero, given that:

$$D = \varepsilon E \tag{2}$$

$$E = -\nabla\varphi \tag{3}$$

With ∇ is the gradient operator so we have

$$D = -\varepsilon\nabla\varphi \tag{4}$$

where ε is the spatial permittivity distribution. E is the electric field intensity and φ is the electric field potential distribution within the sensor. As in Equation 4 into Equation 1 giving Poisson's equation [12] [13]:

$$\nabla \cdot [\varepsilon 0\ \varepsilon\ (x, y)\nabla\varphi(x, y)] = 0 \tag{5}$$

Where,

ϕ (x, y) − spatial potential distribution
ε0 − permittivity constant of free space
ε (x, y) − spatial permittivity distribution
∇· − divergence operator
∇ − gradient operator

3. Common and Parallel Approach Method

Generally, the ECT is one of the soft field types of tomography and the most suitable method to apply in this type of tomography is common approach. This common approach is also known as fan beam projection [14]. Alternately, the parallel approach, is used in hard field tomography application [15]. There are differences between these two approaches. In addition, common approach has one excite electrode, same as parallel approach which is both are set with the electrical potential. In the receiving part, other electrode is connected to the ground. So, it consists of fifteen (15) receiver electrodes in common approach while parallel approach only has one receiver electrode. This is because the parallel approach projection only consists of one exciting and one receiving electrode.

3.1 Common Approach

Usually, almost of the application of ECT using this method because of its less complexity [10]. Figure 2 shows the projection of a common approach for first excitation.

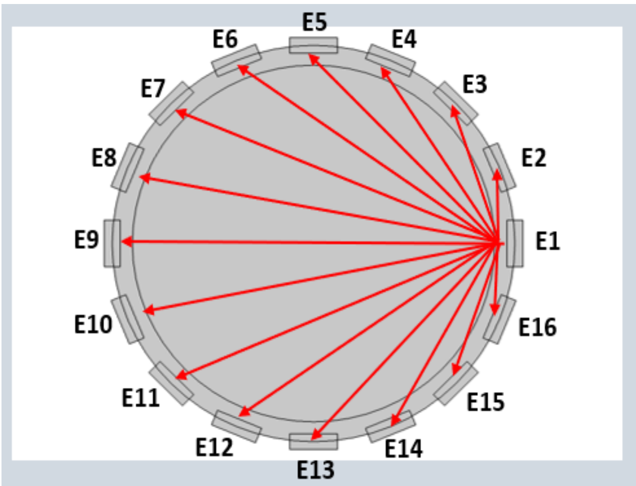


Figure. 2. Projection Flow of Common Approach

After first excitation is done, the procedure is repeated until the cycle is completed. The total excitation will be sixteen (16).

3.2 Parallel Approach

In parallel projection, the arrangement of electrode needs to be rearranged to ensure the excited electrode is paired on the correct receiver in parallel way. Figure 3 shows the projection of parallel approach for its first excitation.

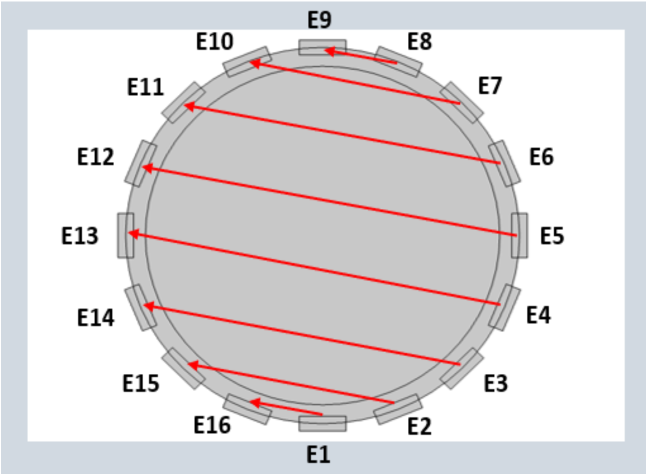


Figure 3. Projection Flow for Parallel Approach

The arrangement of the electrodes like in figure 3 makes a researcher easier to pairing between the excitation electrode and the receiver. After the eight projection is done, the receiver electrode changes to be the excitation electrode and simultaneously, the excitation electrode will be the receiver in order to complete the cycle. So, the total excitation is sixteen (16) same as common approach method.

4. Simulation Set-Up

In creating and simulating a model using COMSOL Multiphysics, a specific dimension, physics and study type need to be specified. COMSOL Multiphysics has been chosen because it can go the coupled processes or system involving more than one simultaneously occurring physical fields and the studies and knowledge about these processes and systems. This simulation study uses electrostatic interface under a branch of AC/DC model. It can produce an electrical field and has the electrical potential value required for the analysis.

Sixteen rectangular electrodes (E1-E16) were implemented and it was attached along the circumference of the non-conducting pipe as shown in figure 4. Since sixteen electrodes are used, it needs to position equidistantly to ensure the system can simulate maximum amount of information.

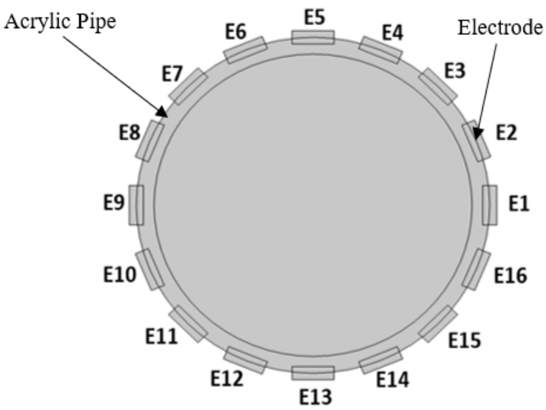


Figure 4. Geometry for the simulation in COMSOL Multiphysics

The applied parameters in simulation are shown in Table 1.

Table 1. Parameters of the model

Item	Value
Inner diameter of plastic pipe	54mm
Outer diameter of plastic pipe	60mm
Thickness of plastic pipe	3mm
Type of electrode	Copper
Number of electrodes	16
Width of electrode	7.1mm
Excitation Voltage	22v

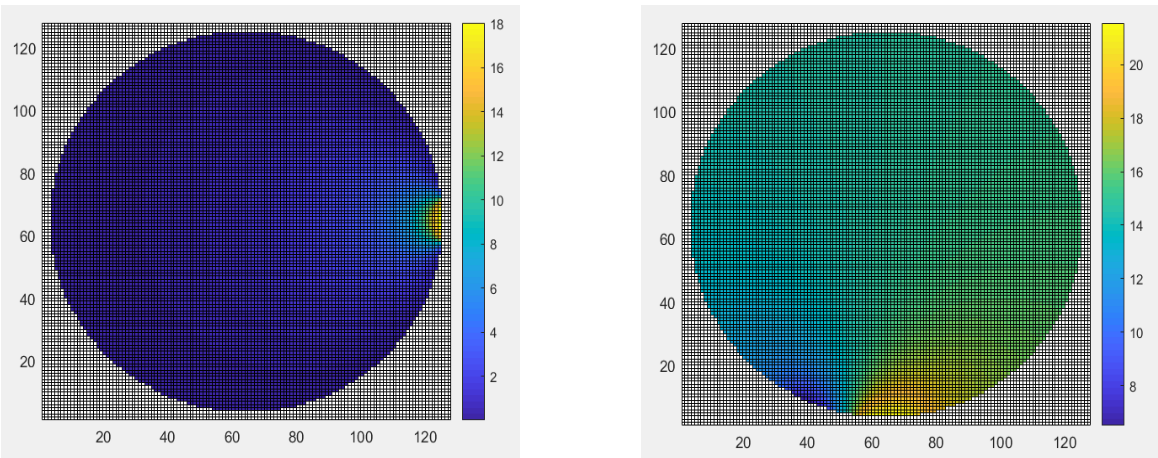
The details for each material used are shown in Table 2.

Table 2. Properties of material in the simulation

Material	Electrical conductivity, S/m	Electrical conductivity
Copper	5.977e-6	1
Acrylic plastic	3e-14	2
Oil	Null	3
Air	10e-15	1

In common approach, for the first excitation, the electrode 1(E1) boundary was selected for transmit electrical potential. Then, the acrylic plastic pipe and the outer electrode were set to V=0 (as ground). The process was repeated until all channels were set as transmitter and receivers. In contrast to the common approach, for the parallel approach, the arrangement of the electrodes was changed in order to make it easier to pairing the electrode between the transmitter and the receiver as shown in figure 3. Since the arrangement was changed for parallel mode, the selection and boundary probe from electrode 1 until electrode 16 were changed as the sequences of the arrangement to ensure the simulation cycle is completed following the number of electrodes. The set-up of the ground also need to be modified in order to follow the principle of the parallel approach. The ground needs to be set one by one for each projection following the pair of electrodes.

For sensitivity map, the data result obtained when the pipe is full filled with oil (homogenous) in COMSOL Multiphysics was exported to be imported in MATLAB. It is done to proceed for the image reconstruction process. The data with electrical potential expression was exported as 128x128 pixels file. Figure 5 shows the example of sensitivity distribution of electrical potential from common approach for first excitation and figure 6 shows the example of sensitivity distribution of electrical potential from the parallel approach for first excitation.



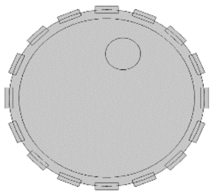
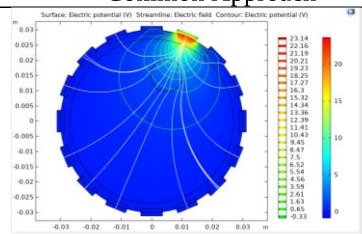
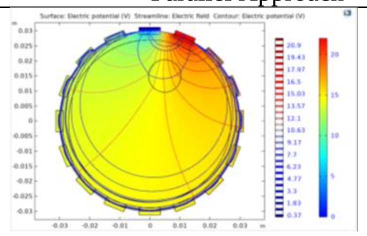
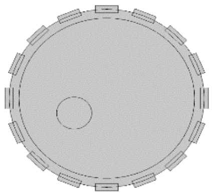
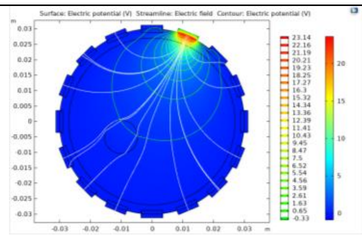
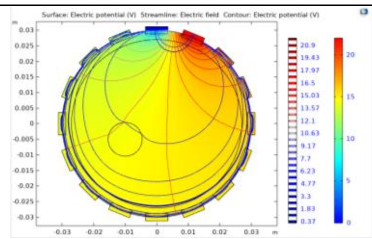
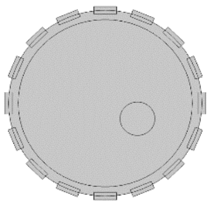
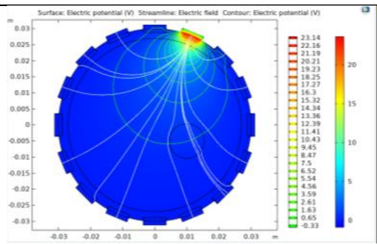
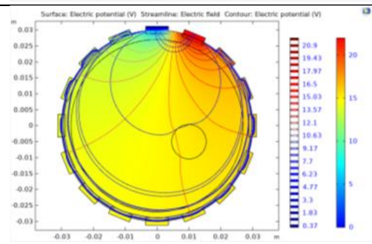
(a) (b)

Figure. 5. Sensitivity distribution of (a) common approach versus (b) parallel approach for first excitation

5. Results and Discussion

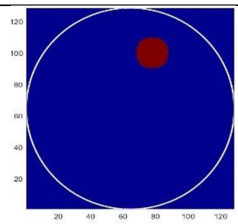
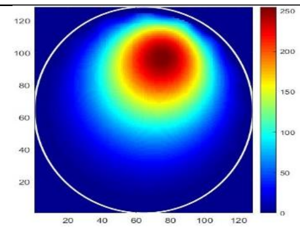
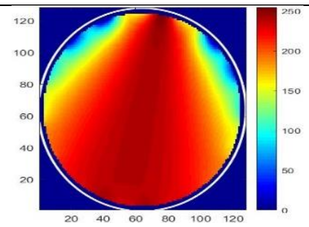
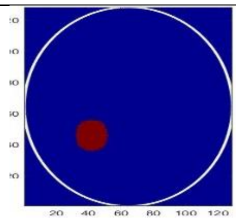
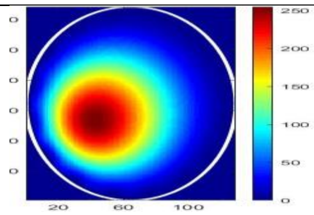
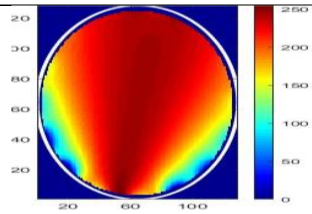
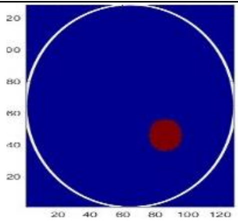
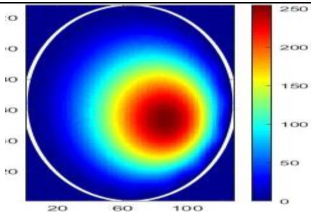
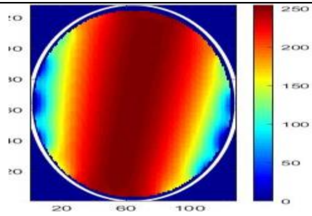
For this simulation, the subject with same obstacle with 7 mm in diameter and different positions were tested with different method of projection, common versus parallel approach. Table 3 shows the result for three different positions of the obstacle which are at the top right, bottom left and bottom right for both approaches. For common approach, the electrical field and equipotential line (black lines) are clearly seen at the excitation channel only because all other receivers were set at ground. Meanwhile in the parallel mode, the electrical field and equipotential lines are high between the excitation and one receiver only because of there are only 1 receiver (grounded electrode) and other channels were floating for every excitation. In addition, the electrical potential streamline (red lines) still distorted when passing through the air obstacle for both approaches. Moreover, the electrical potential streamline was observed flowing through the non-conducting pipe because of it different of permittivity between the pipe and the medium inside.

Table 3. The effect of obstacle positions

Geometry	Common Approach	Parallel Approach
 Top right		
 Bottom left		
 Bottom right		

In the same way, the image reconstruction for the same obstacle with different positions were obtained and analysed. Table 4 shows the tomograms of the different position of obstacle which were top right, bottom left and bottom right. The multi scale structural similarity (MSSIM) from Ref. [16] was applied to observe the performance of the tomograms obtained for both approaches. Based on Table 4, it was proven that LBP was able to generate tomogram with different position of obstacle. When the parallel projection was simulated for this condition, the tomograms obtained just triggered the nearest electrode to obstacle instead of provided the specific location of the obstacle. The MSSIM index for parallel tomograms shows the lower value compared to the common tomograms because of the poor results for the parallel projection method.

Table 4. The image reconstruction for different position of obstacle

Position	Reference Image	Common Approach	MSSIM	Parallel Approach	MSSIM
Top right			0.2411		0.1186
Bottom left			0.2037		0.1174
Bottom right			0.2048		0.1158

6. Conclusion

In short, the quality of image was dropped due to the smearing effect especially in parallel approach. The basic idea came from the parallel projection method that used in optical tomography as in Ref. [15]. This projection in hard-field application used higher number of electrode because the electrode is non-trans receiver where the excitation electrode cannot be set as a receiver (grounded electrode) at specific excitation. Same goes to the receiving electrode where it cannot be set as excitation electrode for certain excitation. Overall, the parallel approach needed a further study to produce a good tomogram. This is because the current LBP need to be modified in order to follow the principle of parallel projection method.

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