An introduction of two differential excitation potentials technique in electrical capacitance tomography


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A B S T R A C T

The investigation of this work is to analyse the sensitivity distributions using single and two differential excitation potentials techniques in order to improve the situation of: (1) non-uniform sensitivity distribution; (2) less sensitivity in the central area and (3) non-linear change in the ECT (electrical capacitance tomography) system. Forward modelling using COMSOL. Multiphysics is developed in order to obtain an algorithm to quantify the image reconstruction. The forward model developed is to simulate the changes in capacitance between opposing electrodes and the permittivity of the dielectric material due to the increasing of the diameter of a permittivity insert when two differential excitation potentials were injected. The MATLAB simulation is used to obtain the sensitivity distribution inside the closed pipe from the sensor. By using the MATLAB software, the forward model conditions are placed on the image plane to estimate the results. Generated phantoms and measured values are presented. Simulation is verified using available experimental data through the existing system, sixteen-segmented ECT sensor electrodes. By using this technique, linear relationship between the capacitances measured and the permittivity dramatically improved, and the sensitivity distribution for an opposing electrode pair was increased; thus giving a slight increase in the sensitivity distribution in a central area. Simulation and initial experimental results illustrate the capability of the technique presented.

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1. Introduction

Initially, tomography was applied in the medical field for diagnostic purposes. In medical applications, X-rays were used as a radiation source to form images of bones based on their attenuation coefficient. This approach allows us to ‘see’ the internal structure (bones) of our body without ‘opening’ it. Therefore, a tomography approach is also known as a non-invasive method to investigate the internal structure or behaviour of a material. It has to be emphasised that the concept of tomography is not restricted to the medical field. This fundamental difference results in differences in sensor design, imaging speed, image reconstruction algorithms and also cost [1].

Electrical capacitance tomography (ECT) is the most mature among many different industrial tomography modalities. It has been developed rapidly and used successfully in many applications, mostly for multiphase flow measurement. Research work has proven that this technique is one of the most attractive and promising methods for the measurement of two-phase flow because of its non-invasion, reliability, simplicity and high-speed capabilities [1-3]. There are three principal difficulties with image reconstruction for ECT: (1) the relation between the permittivity distribution and capacitance is non-linear and the electric field is distorted by the material present, the so-called ‘soft-field’ effect [1, 2, 4]; (2) the sensitivity in a different location between the electrode pair does not give a uniform sensitivity distribution. Note that the maximum sensitivity of an adjacent electrode pair is 100 times larger than an opposing electrode pair [1]; and (3) the sensor is more sensitive in the wall area than the central area, and consequently, the signal-to-noise ratio (SNR) in the central area is poor. This effect will cause the mutual capacitances to be too small; thus the electrode charges

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(and their change) can also be very small, and as a result, the SNR of the measurements tends to be rather poor [5].

An ECT sensor consists of a set of measurement electrodes mounted symmetrically inside or, more typically, outside an insulating pipe. In the conventional measurement scheme, only one voltage source is applied to each of the sensor electrodes in turn with the remaining electrodes kept at ground potential, and the capacitances between all electrode pairs measured. This is called the single-electrode excitation scheme, and the electrical field distributions of the sensor can be seen in Fig. 1(a) using a single-electrode energized within a 12-electrode sensor.

It has been stated that the sensitivity is proportional to the electrical field strength. To improve the sensitivity and SNR (signal-to-noise ratio) in the central area, a scheme called parallel field excitation has been proposed previously by [4,6,7], in which the parallel field is generated by applying excitation signals to all electrodes. However, if excitation signals are applied to multiple electrodes, it is possible to generate a parallel field with an ECT sensor as shown in Fig. 1(b). The sensitivity maps of a parallel-field ECT sensor are simply linear superimpositions of the sensitivity maps of the conventional ECT sensor, and a parallel-field ECT sensor does not give a uniform sensitivity distribution. This has been confirmed by theoretical analysis, software simulation and experiments [1].

In the case of a sensor with internal electrodes, the components of capacitance due to the electric field inside the sensor will always increase in proportion to the material permittivity when the sensor is filled uniformly with higher permittivity material. The wall has a negative effect on the measurement of the internal capacitance because the wall capacitance is effectively in series with the internal capacitance [4]. However, for sensors with external electrodes, the permittivity of the wall causes non-linear changes in capacitance, which may increase or decrease depending on the wall thickness and the permittivities of the sensor wall and contents [8].

From previous studies there are no techniques to improve the uniform sensitivity distribution in the central area and improve the level of the detection signals in the ECT system using single-electrode excitation and one voltage source. Thus, the focus of this work is to analyse the sensitivity distribution and non-linear changes of capacitance due to increasing the diameter of the higher dielectric material. Instead of using only one potential excitation/voltage source to an excitation electrode at a given time, a two difference potential excitation/voltage source, applied sequentially to difference excited electrode pairs, is introduced, to produce an approximately uniform excitation field across the sensor. The simulations of image reconstruction are presented to show the capability of these techniques in improving the sensitivity distribution in the central area. These techniques have not been used before in an ECT system. The increase in voltage across the centre of the pipe should improve the SNR (signal-to-noise ratio) compared to that achieved using standard single excitation potential schemes.

2. Modelling process using COMSOL Multiphysics

For most practical ECT sensors, there is not a simple linear relationship between the capacitance measured at the electrodes and the permittivity of the material inside the sensor. The relatively large number of different measurements required and the fact that the relationship between capacitance and permittivity may be different for each of these measurements creates potential calibration and operating problems for ECT systems. The relationship between capacitance and permittivity distribution is governed by the following equation:

$$C = \frac{Q}{V_c} - \int \epsilon(x,y)\sqrt{q(x,y)}ds$$

where $\epsilon(x, y)$ is the permittivity distribution in the sensing field, $V_c$ is the potential difference between two electrodes forming the capacitance, $q(x, y)$ is the potential distribution and $ds$ is the electrode surface or close line.

However, the permittivity distribution is generally not uniform [2]. In ECT this is usually referred to as a forward problem. A forward problem is the process of determining the output response of an ECT system when the permittivity distribution is known.

Thus, this non-linear forward problem has been simplified to a linear approximation. The method which is commonly used to overcome these problems is to restrict the use of ECT to the case where the sensor contains mixtures of two materials of differing permittivities and to operate the ECT system between the range of permittivities of these two materials. This is done by calibrating the sensor before any measurements are commenced and involves first filling the sensor with the lower permittivity material and measuring all the inter-electrode capacitances and then repeating this operation with the higher permittivity material. All subsequent capacitance measurements are then referenced (or normalised) to the values measured at calibration. For example, all the capacitances have normalised values 0 when the sensor contains the lower permittivity material and 1 when the sensor is filled with the higher permittivity material. For all other conditions, the capacitances will have values which nominally lie between these two measurement limits.
The image pixel values are also normalised in a similar manner so that they have the values zero and one when the sensor contains the lower and higher permittivity materials, respectively. The non-linear image reconstruction is the inverse problem which is beyond the scope of this paper.

In this work, we introduce a new scheme called two differential potentials excitation techniques to be used to improve the non-linear forward problem in soft-field ECT. In this case, two differential excitation potentials are applied sequentially at difference excitation electrode pairs to produce an approximately uniform excitation field across the sensor. To verify this technique, the forward model using COMSOL Multiphysics is developed to simulate the changes in capacitance between opposing electrodes and the permittivity of the dielectric material due to increasing the diameter of the higher permittivity insert.

Simulation is verified using available experimental data through the existing system. Fig. 2(a) depicts the 16 electrodes sensor arrangement which was fabricated and mounted symmetrically on the outer surface of an insulating horizontal pipeline with electrode stretch angle $\theta$ of 22.5° as illustrated in Fig. 2(b), while Fig. 2(c) shows the complete module of 16 electrode sensors on pipelines that has been designed to cover an acrylic pipe 11 cm in diameter with wall thickness of 0.5 cm, where $R_1$ is inner pipeline radius of 5 cm and $R_2$ is an outer pipeline radius of 5.5 cm [9,10]. The detail of the physical sensor can be found in Table 1.

The linear finite element method (FEM) using COMSOL Multiphysics is used to obtain the capacitance between electrodes when an electric field is applied and to obtain the permittivity distribution inside the closed pipe from the sensor. COMSOL Multiphysics (formerly FEMLAB) is a finite element analysis, solver and simulation software package for various physics and engineering applications, especially coupled phenomena, or multiphysics. The creation of a capacitance sensor model in COMSOL aims to use numerical calculation to determine the electric potential ($\phi$) within the sensor. The sensor model will be used to simulate a real sensor. This means

<table>
<thead>
<tr>
<th>No</th>
<th>Item</th>
<th>Parameter</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Num of electrode plate</td>
<td>16</td>
</tr>
<tr>
<td>2</td>
<td>Electrode length</td>
<td>100 mm</td>
</tr>
<tr>
<td>3</td>
<td>Inner pipe diameter</td>
<td>100 mm</td>
</tr>
<tr>
<td>4</td>
<td>Outer pipe diameter</td>
<td>110 mm</td>
</tr>
<tr>
<td>5</td>
<td>Permittivity of the dielectric</td>
<td>$\varepsilon_r = 80$ (water); $\varepsilon_r = 1$ (air); $\varepsilon_r = 3$ (oil)</td>
</tr>
</tbody>
</table>
it will be able to solve the ECT forward problem in calculating capacitances between all possible electrode pairs.

The design process for an ECT sensor model consists of the following steps: geometry generation according to dimensions to be simulated, boundary conditions assignment, and assignment of physical conditions in sensor sub-domains or zones. The design process for 16 portable electrode sensor models can be divided into the following approach:

i. Choosing the mode in the electrostatics module.
ii. Geometry modelling according to dimension to be simulated.
iii. Generating the mesh.
iv. Setting electrical properties in the domains.
v. Setting the boundary conditions.

The first step to develop the numerical modelling is drawing the shape of a pipeline which is a circle with a certain diameter, as illustrated in Fig. 3. For this case, the drawing geometry used will follow the hardware actual size and geometry as shown in Fig. 3(b). Then, alteration of the number of electrodes around the pipeline can be easily built.

The potential \( \varphi(x, y) \) is calculated using the finite element method (FEM). By using this method, an approximation to the potential \( \varphi \) will be obtained in the sensor at a finite set point corresponding to the nodes of the triangular mesh shown in Fig. 2(a) that is normally used in the finite-element method. Once the potential distribution is found within the sensor, the electric charge \( Q_i \) on each detector electrode is calculated by using Gauss’s law as in Eq. (2):

\[
Q_i = \int_{S_j} (\varepsilon(x, y) \nabla \varphi(x, y) \cdot n) \, ds
\]

(2)

\( S_j \) is a closed curve surrounding the detector electrode and \( n \) is the normal vector along \( S_j \). The potential distribution calculation \( \varphi(x, y) \) by the FEM, as well as the \( Q_i \) solution in this work, is directly implemented with COMSOL Multiphysics. Finally, the capacitance can be computed by an energy method. The energy required to charge a capacitor is given by the expression (3):

\[
W_e = \frac{Q^2}{2C}
\]

(3)

That is equal to the energy of the electrostatic field. This is accessible in the electrostatics module of COMSOL Multiphysics. So, the capacitance is easily obtained as follows:

\[
C = \frac{Q^2}{2W_e}
\]

(4)

Fig. 3. (a) FEM meshing 2D and (b) 3D geometry of portable ECT.

Fig. 4. (a) Potentials distribution and electrical field line for 2D simulation result shows the electric field lines are deflected depending on material distribution, when one electrode was excite.
In this work, the geometry includes the spatial discretisation of the inner part of the sensor. A $32 \times 32$ square matrix has a total of 1024 pixels, but only 830 pixels contribute to representing the image plane, and another 194 pixels lie outside the pipe boundary. Fig. 3(a) shows the finite-element meshing in 2D and Fig. 3(b) shows 3D geometries of the portable ECT as they appear in COMSOL Multiphysics. The meshing as in Fig. 3(a) is performed with different parameters for each zone in order to get a consistent definition in the area to be visualised and a much higher definition near the electrodes, where more accuracy electrode-pairs are needed by means of the method described in.
Simulations and experiments are performed to compare the sensitivity and potentials distribution by using two differential excitation potentials compared using the conventional technique using only one excitation potentials.

3. Simulation setup

3.1. Single excitation potentials

To verify a simulation, firstly a single excitation potential, single-electrode excitation scheme was injected. The electric field and potential distribution for 2D simulation, when electrode 4 is excited, is illustrated in Fig. 4(a). An annular phantom was created and the phantom used in this case is as illustrated in 2D, where a 20 mm in diameter at coordinates x = 60 mm and y = 125 mm as shown in Fig. 4(b). As it can be seen, the simulation result shows the electric field lines are deflected, depending on material distribution.

3.2. Two different excitation potentials

In this work, we introduce a new scheme called two difference excitation potentials techniques. A two difference voltage source is applied at difference excitation electrode pairs. In the first step, to obtain a complete set of data for one image, the first electrode (electrode 1) becomes the excitation electrode/source electrode (which is supplied with a sine wave), while all the other electrodes act as receivers, and receive the capacitor value corresponding to the dielectric in between. For example, capacitances between electrodes 1 and 2, 1 and 3, 1 and 4 until the adjunction electrode, electrode 1 and 14, 1 and 15 and the last electrode 1 and 16 are measured in parallel. In this case, when electrode 1 was injected by the source, electrodes other than electrode 1 are at the virtual earth potential imposed by the transducer and they are called the detecting electrode.

During this measurement phase, electrode 1 was injected by two differential excitation potentials/voltage sources (4 Vpp and 24 Vpp) sequentially, where the lower excitation voltage source 4 Vpp will excited to receive adjunction electrode pairs, for example 1 and 2, 1 and 3, 1 and 4 also 1 and 14, 1 and 15 then 1 and 16, while an opposing electrode pair, in this case electrode 5 until electrode 13, will receive a high voltage excitation source of 24 Vpp. In the next step, electrode 2 acts as excitation and electrodes 3–16 are used for detection, obtaining 15 capacitance measurements. This process continues until electrode 15 is used for excitation and electrode 16 for detection, which obtains only one capacitance measurement. In this case, there will be 120 independent capacitance measurements. In general, the number of independent capacitance measurements is governed by \( K(N - 1)/2 \), where \( N \) is the number of electrodes.

Fig. 5 shows the simulation by two differential excitation potentials using COMSOL Multiphysics, which started with electrode 1 becoming the excitation electrode, followed by electrodes 2, 3, 4, 5, 6 etc. The blue colour shows the receiving adjunction electrode receives lower excitation potentials showing lower concentration while the other electrodes receive higher excitation potentials with higher concentration.

3.3. The comparative analysis of increasing the diameter of the higher dielectric material using single and two different excitation potentials

Next, the simulation was carried out by increasing the diameter of the higher dielectric material for both schemes. Taking the annular phantom into consideration, the effect of increasing the diameter is analysed to find out the linear relationship between the capacitances measured and the higher permittivity insert. The simuktion is shown in Fig. 6. Electrical field lines tend to follow the shape of the phantom with the increasing diameter of higher permittivity.

4. Experimental setup

Experiments are performed using circular containers from 20 to 80 mm diameter. An annular water/air flow phantom was created in the ECT experiments using a few sizes of bottle and test tube. This was achieved by inserting the containers of water inside the ECT sensor, leaving the space between the inner ECT sensor wall and the containers filled with air. The water used in the ECT experiments is tap water with relative permittivity, \( \varepsilon_r = 80 \).

4.1. Single excitation potential technique

According to the 16 segmented sensor arrangement in Fig. 2(a), 24 Vpp voltage is applied to electrode 1 while keeping all the others...
at zero potentials; and the charges on opposing electrodes to the
adjunction electrode, which is the last electrode, are measured from
Eq. (1). These measurements (divided by the excitation voltage)
directly represent \( C_{2-1} \). Next, the excitation voltage is applied
to electrode 2 while keeping all the others at zero and the charge on
electrodes 3–16 is measured, representing \( C_{3-2} \). This procedure
is repeated applying voltage to the electrode \( n \) and measuring
the charge on the electrodes up to 16, until, as a final step, voltage
is applied to electrode 15 and the charge of 16 electrode is mea-
sured. In this way, 120 independent mutual capacitance values are
produced. Fig. 7 shows the potential distribution measured with no
water in the phantom and water in the phantom.

Based on the output voltage, it can be seen that for the non-
uniform distribution, the highest value of the voltage happens at
electrode pairs 1-2 and 1-16 for the first channel. This tells us
that the adjacent pair of the electrode will cause a high stand-
ing capacitance. Meanwhile, the lowest value happens at electrode
pair 1-9, as the distance between pairs is escalating the standing
capacitance will be reduced. Based on electromagnetic theory, this
scenario happens when the nearest two conducting materials with
any dielectric material between them produce a higher density of
magnetic field, and therefore generate a higher standing capaci-
tance. Even so, its shows that the standing capacitance may change
due to the material that fills the pipeline.

4.2. Two difference excitation potentials technique

In this case, a 4 Vpp and 24 Vpp voltage is applied to electrode 1
alternatively, while keeping all the other electrodes at zero poten-
tial until electrode 2 turns to the excitation electrode. During
the excitation time, voltage sources are switched sequentially where
the lower excitation voltage source 4 Vpp will excited to receive
adjunction electrode pairs, for example; 1 and 2, 1 and 3, 1 and 4,
and also 1 and 14, 1 and 15 then 1 and 16, while opposing electrode
pairs, electrode 5 until electrode 13 will receive a high voltage ex-
citation source of 24 Vpp. The potential distribution for an opposing
electrode pair was increased, improving the sensitivity distribution
in the central area slightly as shown in Fig. 8.

The increase in voltage across the centre of the pipe should
improve the level of the detection signals or SNR (signal-to-noise
ratio) in ECT system. Thus improving the sensitivity distribution
in the central area. The sensitivity distribution is simply the sensor
response map to a small single area of high permittivity material
in a low permittivity background as it is placed all over the sensing
area [4].

5. Simulation and experimental results

5.1. Simulation results

The permittivity distribution in the simulations was verified.
The 2D corresponding 3D geometries of the ECT are illustrated in
Fig. 13. The Capacitance is measured between the model electrode
pairs and the electric field distribution for 2D and 3D simulations,
when electrode 4 is excited. The phantom used, as illustrated in
Figs. 9(a) 2D and (b) 3D, used a 50 mm diameter cylindrical phan-
tom of water surrounded by air, which is located with its centre at
coordinates \( x=70 \) and \( y=130 \). As it can be seen, the electric field
lines are deflected, depending on material distribution.

Results increasing the diameter of the higher dielectric mate-
rrial for both schemes are simulated as Figs. 6(a) single and (b) two
different excitation potentials. The image shows the electric field
lines tend to follow the shape of the phantom with the increasing
dielectric diameter. Fig. 10 shows the capacitance changes between
opposing electrodes as well as the dielectric material permittivity
with single excitation schemes. The red line shows the standing
capacitance which non-linear changes as a result of the permit-
tivity material size increase are presented in data collected. The
capacitance components reacting to the electrical field within the
sensor will increase in proportion at all time to the material permi-
tivity for a sensor with internal electrodes. This is provided if the
sensor is filled with uniformly higher permittivity material. On the
other hand, the wall permittivity will initiate non-linear changes
in capacitance for the sensor with external electrodes. This might

![Fig. 7.](image1)  
![Fig. 8.](image2)  

![Fig. 9.](image3)  

*Fig. 7. Potential distribution for the low-permittivity (phantom empty) and high-permittivity (phantom full) in pipeline using single potentials excitation.*

*Fig. 8. Potential distribution after normalisation for the low-permittivity (phantom empty) and high-permittivity (phantom full) in pipeline using two different excitation potentials.*

*Fig. 9. Results from (a) 2D and (b) 3D simulation, respectively Blue area is sensing region represents air (\( \varepsilon_{air} = 1 \)), and red area represents water (\( \varepsilon_{water} = 80 \)). (For interpretation of the references to color in this figure caption, the reader is referred to the web version of the article.)*
Fig. 10. Simulated capacitances due to increasing the size of permittivity of the dielectric material, $\varepsilon_r = 80$, using single potentials/voltage source schemes. (For interpretation of the references to color in this figure text, the reader is referred to the web version of the article.)

increase or decrease which is determined by the thickness of the wall as well as the permittivity of the sensor wall and contents.

Next, the simulation was carried out using two different excitation potentials. The image indicates that the electric field lines incline to follow the phantom shape alongside the increasing of dielectric diameter. The capacitance changes between opposing electrodes and the dielectric material's permittivity with the use of two different excitation potentials schemes are depicted in Fig. 11. A red line shows the linear regression is sensible for the majority of the reading for Fig. 11. However, whenever the phantom diameter increases, the capacitance will rapidly increase.

The MATLAB simulation is used to obtain the sensitivity distribution inside the closed pipe from the sensor. By using the MATLAB software, the forward model conditions are placed on the image plane to estimate the results. An annular phantom was made and the phantom applied is as shown in the 2D cylindrical phantom of water which mounts by air. The conventional single excitation potential performance and two excitation potential performance for image reconstruction with LBP algorithm is verified on simulated capacitance data of created phantom, Fig. 12 presents the result of the simulation.

Fig. 12 shows a typical sensitivity map of a 16-electrode portable ECT sensor with single-electrode excitation and single electrode detection (Fig. 12(a)) and when using the two different excitation voltage source schemes (Fig. 12(b)). The non-uniform sensitivity in different locations between the electrode pairs was slightly improved, and sensitivity distribution for an opposing electrode pair was increased, which dramatically increased the sensitivity in the central area.

The absolute capacitance which produced from the simulation using COMSOL converts them in matrix $32 \times 32$ so as to acquire the sensitivity distribution, which create a sensitivity map. The sensitivity map is the imaging region that subdivided into small pixels in order to construct the sensitivity matrix and to identify the change.

Fig. 11. Simulated capacitances due to increasing the size of permittivity of the dielectric material, $\varepsilon_r = 80$, using two different potentials/voltage source schemes.

Fig. 12. Sensitivity maps of a 16-electrode portable ECT sensor when (a) single excitation potentials and (b) two different excitation potentials schemes.

Fig. 13. Inter-electrode capacitances measured value due to different sizes of phantom, using two different excitation potentials schemes.
in each pair of electrodes capacitances because of a small dielectric constant perturbation in each pixel.

A 32 × 32 square matrix has a sum of 1024 pixels for this research. However, only 830 pixels promote to denote the image plane while the other 194 pixels placed at the outer part of the pipe boundary. The reconstruction matrix is presented in Fig. 14. The geometry diameter has to be divided into 32-line horizontally in order to make the sensitivity map. However, the electrical charges will be read automatically by the COMSOL vertically. The MATLAB is used to image them in 2D and 3D form when all the values are required. The coordinates of x-axis which is from X2 will be let to increase until coordinate X32 while coordinate of y which is Y1 and Y2 are remained and fixed. The generation of sensitivity map (a) 2D and (b) 3D is depicted in Fig. 15.

5.2. Experimental results

To analyse the linear relationship between the permittivity distribution and capacitance, the inter-electrode capacitance value is measured using Digital Capacitance Metre by GLK INSTRUMENTS. These types of digital metre provide analogue outputs of the metre reading and of the reference voltage for radiometric measurements. These outputs can be connected to digital voltmeters, plotters, data loggers and computer data acquisition systems. As was mentioned earlier, the annular water/air flow phantom was created in the ECT experiments using containers of different diameters of a few sizes of a bottle. This was achieved by inserting the bottle and test tube inside the ECT sensor, and then filled up the bottle and test tube with water, and leaving the space between the inner ECT sensor wall and the outer bottle or test tube wall with air. The water used in the ECT experiments is tap water with relative permittivity, ε_r = 80. The measured value of inter-electrode capacitance by experimental due to difference size of dielectric material can be seen in Table 1 and graphically in Fig. 13. The capacitance values in different sizes of phantom are verified in a range between 0.1 pF and 0.45 pF which indicate in valid range.

6. Simulative study on image reconstruction algorithm

The linear back projection method is chosen in this work to perform image reconstruction. Most of the work in this tomography has also been focused on the use of the linear back projection (LBP) algorithm. The back projection algorithm is also the first analytic method to perform image reconstruction from projection signals in medical X-ray tomography [11]. The algorithm has the advantage of demanding low computation processing. The LBP is computationally straightforward to implement and is a popular method of image reconstruction. The modelled sensitivity matrices are used to represent the image plane for each view. To reconstruct the image, each sensitivity matrix is multiplied by its corresponding sensor reading [12].

By using the MATLAB software, the forward model conditions are placed on the image plane to estimate the image reconstruction. In order to justify the quality of a reconstructed image, a standard phantom flow pattern is required as in [13] so that it can be compared directly with the reconstructed image [14, 15].

The performance of the conventional single excitation potential method for image reconstruction is tested on simulated capacitance data of created phantoms in Fig. 16(a) and compared with the new technique of two differences excitation potential as depicted in Fig. 16(b). Fig. 16(c) shows the image on-line reconstruction of annular water/air flow.

The MATLAB is used to create a simulator which makes a 2D mesh with FEM. The mesh functions as pixels for phantoms. Therefore, the pixels position and size will stay fixed all through the simulation. The graphical user interface (GUI) is created to apply the profile of simulation image reconstruction. The basic LBP algorithm is used without having to be merged with any non-linear forward model method for example to get involves the application of iterative computational methods, or instead the neural network techniques application so as to improved images off-line from captured capacitance measurements. This is to allow the techniques that proposed, two differential excitation potential schemes can complete an issue of non-linearity.
7. Conclusions

Due to the simulation and experiment verification, by using this technique the linear relationship between the capacitance measured inter-electrodes and the permittivity dramatically improved. The non-uniform sensitivity in different locations between the electrode pairs was slightly improved and sensitivity distribution for an opposing electrode pair was increased, which dramatically increases the sensitivity in the central area. By using the new technique, two different excitation potentials, the increase in voltage across the centre of the pipe does increase the level of the detection signals, and improves the SNR (signal-to-noise ratio) compared to those achieved using standard single excitation potential schemes.

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