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Reconstruction Of Image In Electrical Capacitance Tomography

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Abstract

Electrical Capacitance Tomography (ECT) is a non intruding imaging technique that maps dielectric permittivity of materials. The principle is based on inter electrode capacitance measurement, which is done by placing electrodes around a dielectric medium which is generally made of a PVC pipe. The object to be imaged is placed between the dielectric medium. The electrodes are placed around the wall of PVC pipe. The values of capacitance vary with respect to permittivity of the medium, area of the plates and distance between the plates. In this system, we keep the area of the plates and distance between the plates as constant, thus the only factor that affects the capacitance value is dielectric permittivity. These data explains the material distribution inside the pipe and it is used for reconstruction of an image of spacial distribution in the pipe. The capacitance values obtained from the system is used to reconstruct the image and the reconstruction is done in MATLAB. The reconstruction algorithm used in the system is Linear Back Projection Algorithm. The LBP algorithm is based on the solution of a set of forward and reverse or inverse linear transforms.

Keywords- ECT, MATLAB, Linear Back Projection algorithm.

I. INTRODUCTION

Electrical Capacitance Tomography [1][2] (ECT) system is used to obtain spatial distribution of a mixture of dielectric materials within a vessel, by calculate the electrical capacitances between the pair of electrodes wound around the PVC pipe. The measurements are used in reconstruction of image. The image shows distribution of permittivity between the considered electrodes as an image based on pixel. Images

are approximate and of relatively low resolution, however it can be make fast. The applications of ECT include searching the concentration distribution between the considered electrodes.

The intention of the paper is to reconstruct an image using MATLAB with the inter electrode capacitance values.

A. *ECT System*

The Electrical Capacitance Tomography (ECT) system is based on the use of array of 8 electrodes. The electrodes are mounted on a PVC pipe and each electrode is equally spaced and has fixed area. The object or medium to be imaged is placed between the electrodes. For imaging the medium, the measurement circuits are directly connected to the specific electrode. The measurement of inter electrode capacitance value and therefore become a good design solution for ECT sensor. The 8 electrode system can be used in multi phase flow [3] (MPF's) measurement. The sensing methods used in the presented system can measure the capacitance in femto farads and voltage in micro farads. The mode of excitation is multiple excitations which improves the system performance of the presented ECT system. In this paper we shall discuss how the sensitive field models of typical flow were established and the imaging of permittivity distribution were done using MATLAB software. For real time measurement of Electrical Capacitance Tomography system, the dielectric permittivity between the electrodes, which acts as capacitance sensor is determined. The proposed system mainly consists of five parts as shown in figure 1. The main parts are: (1) Sensor system, (2) Capacitance measurement unit, and (3) Computer. Thus the main functions of the ECT system can be described as selecting or receiving the data, measuring each one combination of capacitance values and saving them. On finishing it, it reconstructs and displays the image created based on the measured values.

The first part of ECT system, which is the sensor contains the electrodes mounted vertically around the PVC pipe. The sensor measures the capacitance for all possible electrode combinations. The system is made of an array of electrodes which substantially improves the speed of the overall system. The eight electrodes that act as capacitor plates are arranged as in figure 2.

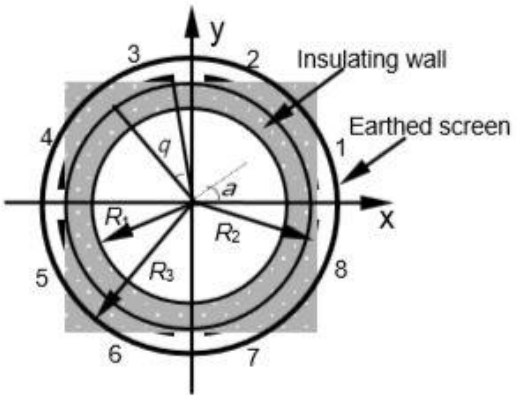

Figure 2. Arrangement of electrodes.

The second part of the ECT system is capacitance measurement unit, which measures the inter electrode capacitance between the electrodes. The signals obtained while measurement are very weak and contain noise, so they need to be strengthen and purified for further processing. Hence an amplifier is provided to strengthen. The noise is reduced by passing the signals to signal conditioning unit and the signal controller unit, for the normalisation of signals. An excitation signal of very small frequency is also attached to the system. A low pass filter is also provided in the system to filter out the high frequency noise signals from the system.

The third part of the ECT system is computer which is used for reconstruction of images through any software. The software used in the proposed system is MATLAB software. The computer accepts only digital signals; hence it is connected to the ECT system using NI DAQ 9871. The DAQ is a data acquisition device that reads the data from ECT and gives the values to computer. The voltage values need to be converted in to corresponding capacitance values for imaging of the medium. This conversion is done by an online method called online Multiple Regressive formula. We enter the obtained values into the formula, and we will get the corresponding capacitances values. Then using the capacitance values obtained, we construct permittivity distribution images. For a 8-electrode system, there are 28 different voltage values obtained from different combination of electrode pair which acts as source and detector. The voltage values have a linear relation with capacitance in the presented system. Thus the corresponding capacitance values are mapped onto a square grid containing 1024 pixels (32 pixel x 32pixel) to graphically display the permittivity distribution inside the pipe. An algorithm implemented in the computer system is used for imaging of the medium. The control signals that control the process are generated after analyzing the permittivity distribution images obtained through MATLAB.

B. CAPACITANCE SENSORS AND SENSOR FABRICATION

The sensors [4][5] are made of 8 electrode wound around the PVC pipe. The electrodes are rectangular in shape, equally spaced and have same area of cross section. Sensors used in ECT system are designed according to the cross section of the vessel and positioning of electrode. The pipe of the proposed system was non conducting material with the sensors wound around the pipe which are conducting plates. Thus the sensors are non intrusive and easy to design.

The functional base of an ECT system lies in the fact that the changes of measured capacitance values will depend on the material distribution inside the pipe.

Thus the system is not subjected to extreme temperature and high pressure inside the tube. Also, the number of electrodes in a system is inversely proportional to image acquisition rate and overall resolution rate. However, change in each capacitance is directly proportional to change in permittivity inside the pipe.

The sensor constructed here has pipe outer diameter as 24.5mm and inner diameter is 23mm. The total length of the electrode is about 1000 with single electrode width at 1mm.

II. CAPACITANCE MEASUREMENT

Acquisition of capacitance values[6] are done by applying a voltage to one electrode, say electrode 1 while keeping all other electrodes (here electrode 2 to electrode 8) at zero potential. Then charge between each pair of electrode is measured, say electrode 1 and electrode 2. After taking all the possible combinations, consider electrode 2 and give voltage to it. While doing this, keep all other electrodes starting from 3 to 8 at zero potential. Then the charge in these combinations is also measured. This procedure goes on until the electrode 7 is energized and charge in electrode 8 is calculated. Thus at the end of calculation, there will be a combination of $n * \frac{n-1}{2}$ measurements, i.e., here it is n=8. Therefore, the number of possible combinations is $8 * \frac{8-1}{2} = 28$. This shows that, there will be 28 different voltage values instead of capacitance. The measured voltage values may contain noises and extremely small values. This leads to the need of normalisation. Also the effect of errors inside the unit like offset and drift are eliminated. This also makes the calibration of ECT system easy. The basic equation that governs the system is given below

$$C = \varepsilon_0 \varepsilon_r A/d \qquad (1)$$

Since there is linear relationship between voltage and capacitance, the capacitance value can be found out using online regression method. We submit the values of voltage in the online form and we get the relation that exists between the voltage and capacitance. Hence, we can calculate capacitance value from the voltage value measured. The different combination of electrodes that are considered for measurement of inter electrode capacitance is shown in table1.

Table1: combination of measuring electrodes.

Electrode Excited	Capacitance measured
1	C12, C13, C14, C15, C16, C17, C18
2	C23, C24, C25, C26, C27, C28
3	C34, C35, C36, C37, C38
4	C45,C46,C47,C48
5	C56,C57,C58
6	C67,C68
7	C78

The sensing circuit actually gives a current output and the current to voltage converter is used in the system for voltage measurement. The converter circuit is connected to PC using cDAQ9174 and the values are measured using LABVIEW. Using the values obtained, we go for image reconstruction of Electrical Capacitance Tomography system. The image reconstruction algorithm used was Linear Back Projection Method. It is a linear approximation algorithm that gives fast output. The only problem in LBP is that they give a blurred image.

III. IMAGE RECONSTRUCTION

Capacitance sensor is a soft field sensor. In addition, the number of possible independent measurements is very small compared with the number of pixels required for an adequate image. These issues make it difficult to reconstruct good quality images. The most popular image reconstruction algorithm [7][8] is called the linear back projection [9] (LBP). It is based on first obtaining the sensitivity distributions (or sensitivity map) for all electrode pairs, and then linearly super imposing the normalized capacitances using the sensitivity maps as the weighting factors to obtain images. It is simple and fast but the image quality is bad, particularly for a complex permittivity distribution. To improve image quality, a variety of iterative algorithms have been developed, typically, Yang's method based on Landweber's iteration method. Iterative algorithms can produce better images than the LBP algorithms.

The sequence of actions needed to measure the permittivity distribution and reconstruction of image are: a) creation of sensitivity matrix, b) capacitance value measurement and c) construction of image using image retrieval algorithm. There are several limiting feature that lead to difficulty in calculation of permittivity distributions which include limited number of inter electrode capacitance values compared to number of pixel values, soft field effect and creation of sensor sensitivity matrix.

We use linearization techniques for easy implementation of ECT system. For linearization, we generate a system matrix that contains all properties of the targeted system, the sensitivity map shows the sensor response when the electrode. The 28 measured inter electrode values of 8 electrode ECT system should be projected onto a 32x32 square pixel grid to generate the permittivity distribution image. To create an image, we require those pixel values that lie inside the cross sectional view of pipe. The rest of the pixel values will be unused and hence neglected.

IV. SENSITIVITY MAPPING

Proper sensitivity maps[10] should be created for visualising the capacitance changes between the electrodes and this require accurate pixel selection. The distribution of lines has been studied with the help of a reconstructing technique called Linear Back Projection Algorithm (LBPA). The main work in the reconstruction of image is that we have to project the limited values which are 28 in numbers in the proposed system into 812 pixels on a 1024 square pixels grid. It cannot be carried out exactly due to the limited number of data. Hence we go for approximation techniques for the solution of this problem.

Thus the properties of capacitance sensor are calculated for producing a sensitivity matrix. This matrix consists of maps whose values correspond to individual pixel in the square grid that defines the sensor cross section. For each range of permittivity to be measured, we calibrate sensor measuring the entire individual inter electrode capacitance values. The measured data will be stored in calibration data file and all the values are measured. We are already point out here there will be a set of 28 values. These values will be normalised and image will be constructed from these values based on LBP algorithm. This algorithm is fast, however, it gives only an

approximate algorithm. The image is obtained with the approximate algorithm and sensitivity matrix method. If clear image is to be obtained, then go for other reconstruction algorithm like landweber algorithm, iterative algorithm, genetic algorithm, etc.

V. SENSITIVITY MATRIX

The sensitivity matrix [11] is the matrix that provides information of the capacitance change between electrodes based on the dielectric constant of the medium inside the sensor. If we change the medium, corresponding capacitance values also change. If we observe the electric field distribution, we can find the change of capacitance values clearly. It is found that the field is strongest near the excitation electrode and it weakens as it goes away from the excitation electrode. This is shown in figure 3.

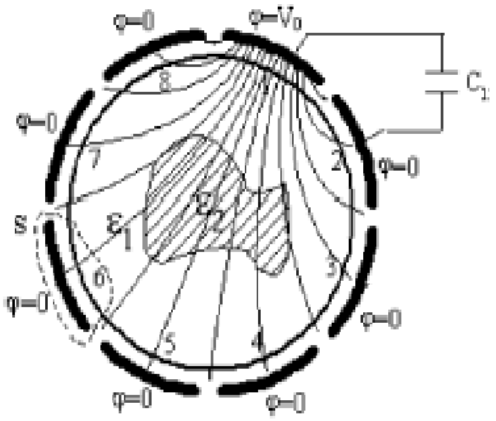

Figure3. electric field distribution inside the ECT sensor.

The uneven distribution is due to the change in permittivity based on the location of object. Thus, it clearly depicts the fact that the ECT system is most sensitive when the object is placed near the walls of pipe and the sensitivity decreases towards the centre of pipe. Thus, when image is constructed by ECT system, it reads the sensitivity mapping and compensates the image pixels accordingly.

We should calculate sensitivity matrix based on each sensor as separate exercise prior using the sensor with ECT. The sensitivity parameter S of a pixel for each electrode pair (i-j) can be calculated by the equation (2).

$$S = Ei.\ Ej.\ dA \qquad (2)$$

where E_i is the electric field inside the sensor when one electrode of the pair i is excited as source and E_j is the electric field when electrode j is excited as a source electrode and dot product of two electric field vectors E_i and E_j is integrated over the

area A of the pixel. The sensitivity coefficients of each pair of electrodes are known as sensitivity map for the corresponding pair.

VI. RECONSTRUCTION OF IMAGE USING LBP ALGORITHM

The Linear Back Projection Algorithm is based on the solution of a set of forward and reverse linear transforms [12]. The two problems concerned are finding the permittivity inside a pipe when the capacitance values are measured which is usually referred to as forward problem. The second problem is to find the capacitance value when the permittivity inside a pipe is known.

A) FORWARD TRANSFORM

The forward transform [13] relates the inter electrode capacitance measurements C to the pixel permittivity values K. In this transform, it is assumed that the measured inter electrode capacitances resulting from any arbitrary permittivity distribution K inside the sensor will be identical to those obtained by adding the component capacitance increases which occur when each pixel has its defined permittivity, keeping all other pixel values at zero. It can be described by the following equation

$$C = S.K \tag{3}$$

Where, C is an (m x 1) dimensioned matrixes containing the set of m inter electrode pair capacitances which are 28 for our system.

K is an (n x 1) dimensioned matrix which is 1024 for a 32 x 32 grid. The values of n describe the permittivity distribution inside the sensor.

S is the forward transform or Sensitivity Matrix of dimension (m x n).

B) REVERSE TRANSFORM

In principle, one set of inter electrode capacitances C is measured, the permittivity distribution K can be obtained from these measurements using an inverse transform Q as follows.

$$K= Q.C \tag{4}$$

Q is a matrix with quantity (n x m) and, according to principle is the inverse of the matrix S. However it is possible to find the true inverse of square matrix S. whatever, it is possible to find the true inverse of square matrix (where m = n). Although exact inverse of matrix does not exist; hence we can use an approximation matrix as a replacement for the LBP algorithm uses transpose of the sensitivity matrix, S'=K with dimension (n x m). We should give value to each pixel proportional to the product of electrode pair capacitance and the pixel sensitivity coefficient for each electrode pair of ECT system. This procedure is finished for full consortium of electrode pairs. The permittivity graph is completed with colour scale for showing normalised pixel permittivity. We can construct the image in MATLAB

and the colour scale can be assigned with standard colouring commands such as jet, autumn, summer, etc.

VII. RESULT

The MATLAB [14][15] is a powerful high level language and hence can display good enhanced of image. It has a good knowledge of libraries and toolbox is necessary in developing the program. Thus, the corresponding coding for reconstruction of image is done in MATLAB. The algorithm used for building is shown in figure (5).

The capacitance values between the electrodes are measured using the voltage values obtained. A voltage signal is first applied to electrode 1 keeping all other electrodes at zero potential. Now the electrode 1 act as source and any other electrode is taken as detector and the inter electrode capacitance of each pair of electrodes is measured. The combinations too like (1-1), (1-2), (1-3)... so on. Likewise all combinations are measured. Thus, there will be 28 different combinations of capacitance values. When the distance between two plates placed are closer, the voltage is high resulting in higher capacitance values. The vice versa is also true.

The normalised capacitance value and sensitivity maps are used to find sensitivity at one plate. After finding sensitivity at one plate, we rotate the plate and similarly find sensitivity at each 45 degree rotation. After this, combination values need to be calculated and plot it in colour code. We can also find overall sensitivity of the system in similar way and produce the overall sensitivity image plot.

The colour scale image obtained with air and water as medium using JET command is shown in figure (6) and (7). In the figure 6, the medium inside the pipe is air. The air has low dielectric constant and low conductivity. The closer the electrode is the permittivity value high. Farer the electrodes, lower is the permittivity distribution. Similarly figure 7 shows the distribution in pipe when water is the medium. It clearly shows when water is medium, the image is blurred. The values were given to MATLAB and the image constructed was in MATLAB coding. The reconstruction algorithm used is Linear Back Projection Algorithm. From the result it is clear that, though the LBP algorithm is easy to use, the image obtained lacks clarity.

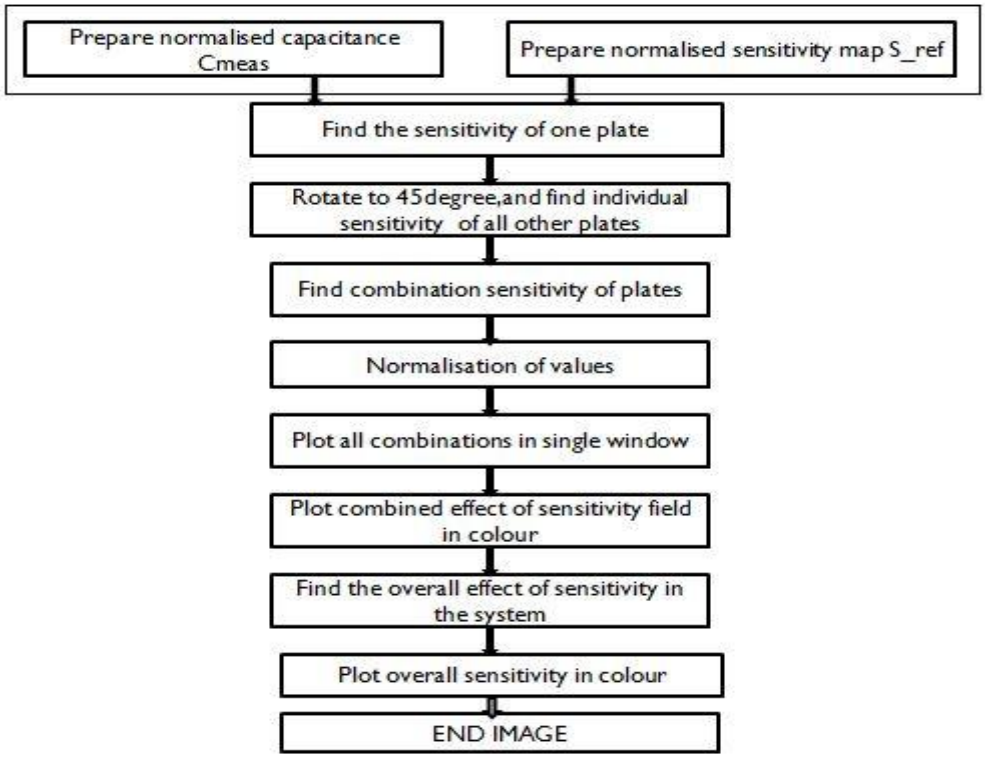

Figure 5. Algorithm for image reconstruction using LBPA

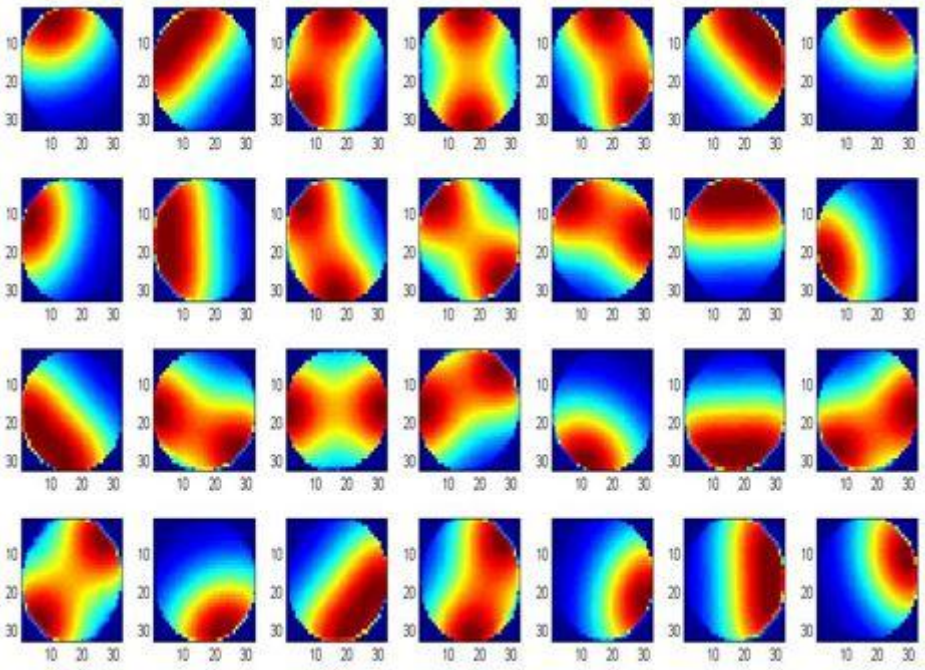

Figure 6. MATLAB obtained in air as medium.

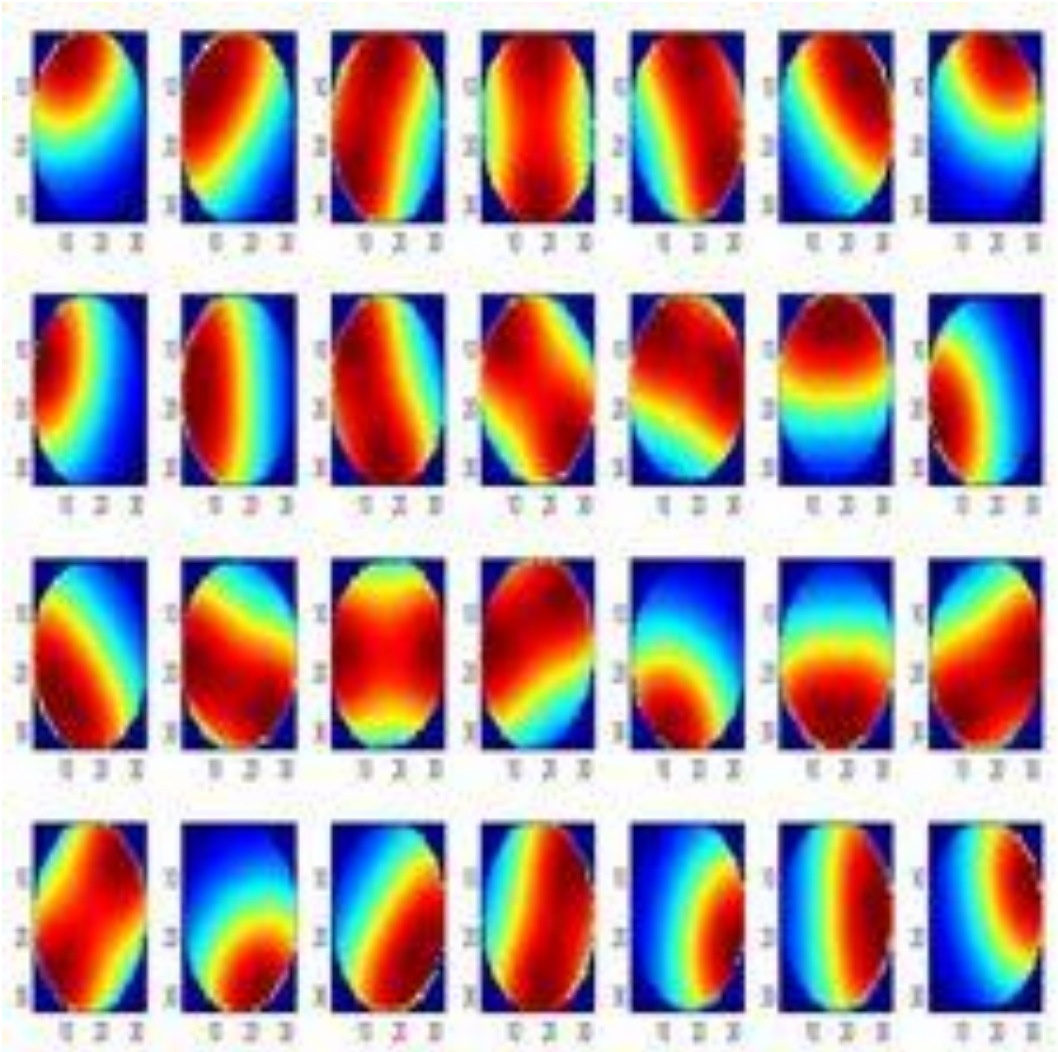

Figure 7:MATLAB obtained with water as medium

VIII. CONCLUSION

The result obtained shows that linear back projection method is fast obtain. The image was made using the 28 values that we compute. The image has 1024 pixels and this is achieved by sensitivity mapping in LBP algorithm. LBPA is an easy method for reconstruction and the speed of capturing is exceptionally high. The algorithm is also useful in calculating the volume ratios, however, the output obtained is blurred and hence its resolution needs to be improved further. Hence we look forward for a reconstruction algorithm that can give clearer image. The image quality can be enhanced by implementing iterative methods. The iterative method calculates errors and continuously iterates the calculations until the error becomes zero. Consequently the image obtained will be of better quality.

Thus ECT system has wide application in industrial and medical field. It has the ability of seeing the chemical process without eyes, if it is properly constructed. However, it requires too faster and efficient algorithms which can provide high resolution image with higher acquisition rates. Though it lacks the ability to gauge flow, proper growth on the system will lead it to be one of the efficient tool in the near future.

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