Initial Study of Electrical Capacitance Tomography for Detecting Agarwood

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ABSTRACT

This study investigates the use of electrical capacitance tomography (ECT) as a non-invasive method to monitor the quantity of agarwood in a tree. Previous methods like sonic, magnetic inductive, and microwave tomography have been used, but it's unclear if voltage variations in resin regions are significant. The ECT system was developed using COMSOL Multiphysics software, modeling 8 electrodes in a 2-dimensional setup. The electrical potential distribution and performance analysis of the ECT model were evaluated for different agarwood locations, shapes, and sizes. The forward problem was solved using COMSOL, and tomogram images were obtained using a linear back projection algorithm in MATLAB. The images closely matched the reference image based on the mean structural similarity index (MSSIM) values. This suggests the potential for accurately reconstructing agarwood images using ECT.

Keywords: Agarwood, ECT, 2-dimensional

1. Introduction

Electrical capacitance tomography (ECT) is a technique for image processing that was developed primarily for industrial purposes. The fundamental premise of ECT is to calculate the difference in permittivity produced by the addition of a new material or a change in the distribution of materials within an ECT system[1]. The ECT sensor is comprised of a number of electrodes, often six, eight, twelve, or sixteen, which are arranged in a round conduction pipe or an insulating pipe around the outside or inside border [2], [3].

ECT is mostly used in industrial applications for two or three-phase measurement of flow parameters [4]–[6]. However, there is no strategy for agarwood in the ECT technique yet. Because ECT is low energy, low frequency, and non-radioactive, it is safe to use in any circumstance, including hazardous waste, high voltage, or electromagnetic radiation [7]. Due to the technology's low energy consumption, it is also useful for rural places with limited access to electricity. Often, a simple solar powered battery will be enough to power an ECT device. For agarwood detection, the current research that had been done by other researchers are only based on simulated magnetic inductive tomography [8] and microwave tomography [9]. As a result, electrical capacitance tomography is proposed in this project whereby the varying electrical permittivity of the agarwood will be the primary concern for this simulation model of the ECT system.

2. Electrical Capacitance Tomography

Electrical Capacitance Tomography (ECT) is a technique used to gather information about the contents of vessels by analyzing the dielectric distribution of the material inside [3]. The concept involves installing a number of conducting plates (electrodes) around the vessel's periphery, and images can be generated based on the signals obtained by these capacitor electrodes [2]. The design of ECT sensors depends on the capabilities of the capacitance measuring equipment used [10]. An ideal capacitance measuring system should have low noise levels, a wide dynamic measurement range, high immunity to stray capacitance, and the ability to perform measurements at high speed [11].

An ECT system typically consists of a set of measurement electrodes symmetrically mounted inside or outside an insulation pipe. It includes a sensor with 6, 8, 12, or 16 electrodes, a capacitance measurement circuit, a central control unit, and a control PC [2], [3]. In specific applications, 6 electrodes are commonly used for visualizing combustion flames in engine cylinders, 8 electrodes are employed for imaging wet gas separators, 12 electrodes are utilized for measuring three-component flows (gas, oil, and water), and 16 electrodes are used for imaging nylon polymerization processes [2], [12]. As initial study, the 8 electrodes was used for modelling the ECT system in detecting the agarwood.

Besides, the 2-dimensional ECT is representing by Poisson's equation as in (1) [13], [14] where the spatial permittivity distribution is denoted by ε and φ is the electric field potential distribution within the sensor.

$$\nabla \cdot (\varepsilon(x, y) \cdot \nabla \varphi(x, y)) = 0 \qquad (1)$$

Thus, for a two-dimensional scenario that includes the x and y axes, the $\varepsilon(x,y)$ is the two-dimensional relative permittivity distribution with boundary conditions equal to $\varphi = V_C$ for the first electrode and $\varphi = 0$ for the subsequent electrodes. This equation is used for 2-dimensional modelling in Comsol Multiphysics software for detecting agarwood.

3. Methodology

This study primarily focuses on the design and simulation of an Electrical Capacitance Tomography (ECT) system for agarwood using COMSOL Multiphysics software. In this context, it is preferable to choose outside electrodes instead of inside electrodes. Figure 1 illustrates an ECT flow measurement system, where the ECT sensor is composed of 8 equidistantly attached electrodes along the periphery of the agarwood tree (wood).

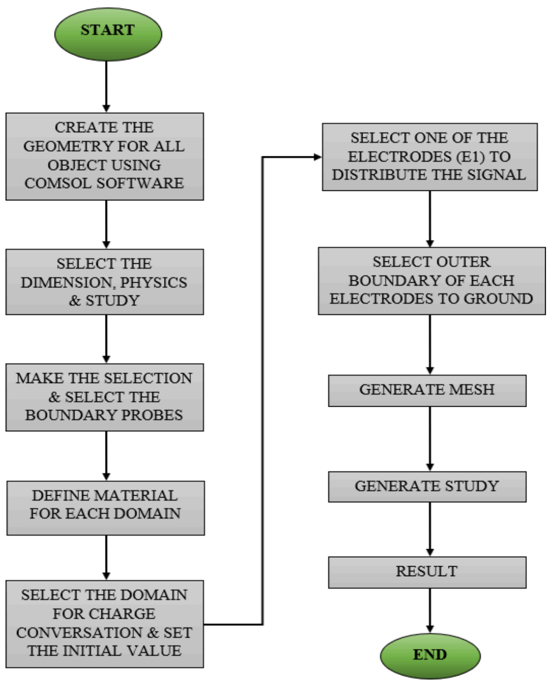

Figure 1. Basic flow process in COMSOL Multiphysics

The simulation of the ECT system using COMSOL Multiphysics for a sensor model with 8 electrodes can be done into the following steps:

i) Selecting the dimension of space, the physics, and the subject of the project topic
ii) Select the electrical value and wave type

iii) Define the bounding conditions
iv) Specify the content that will be used in each domain
v) Set the electrical properties of the domain
vi) Creating the mesh
vii) Generating the study

The two-dimensional (2D) arrangement of the ECT system with 8 electrodes is depicted in Figure 2. To begin the modeling process, the agarwood was assumed to have a circular shape. The specific physical parameters utilized for the modeling are detailed in Table 1.

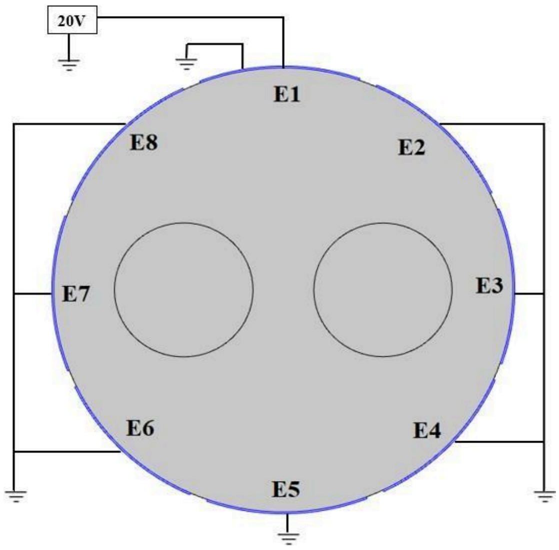

Figure 2. 2-Dimensional geometry model for ECT

Table 1. Related physical parameter used [8], [15]

Domain	Parameter	Value
Wood	Diameter	600mm
	Material	Wood (pine)
	Relative Permittivity, εr	3.17944
Electrode	Number of Electrode	8
	Stretch Angle of Electrode	40.5^{0}
	Thickness of Electrode	2.5mm
	Material	Gold
	Relative Permittivity, εr	1.143
Air	Relative Permittivity, εr	1
Agarwood	Diameter	181mm

	Material	Wood (pine)
Agarwood (Sample A)	Relative Permittivity, εr	2.84180
Agarwood (Sample B)	Relative Permittivity, εr	1.60002
Agarwood (Sample C)	Relative Permittivity, εr	1.71432

The electrical value for the electrode was set by 20Vdc for injected to the electrode source. In this paper, it only focuses on the simulation part so it was decided to use only the dc voltage to avoid complexity in modelling the ECT system. Besides, the dc signal is chosen because it obtained a positive value reading as well as avoiding a very small voltage reading value. Actual presentation of ECT model is shown in Figure 3.

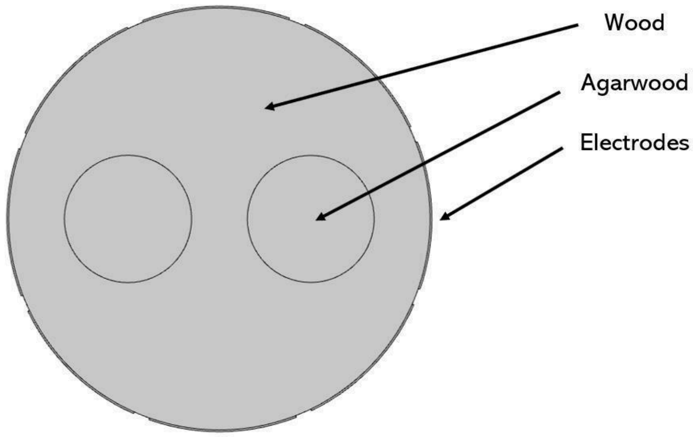

Figure 3. Actual set up signal of ECT model

After that, the mesh of ECT model was generated. In this simulation, it used a fine mesh of element size. The geometry is classified according to its shape or element type, the geometry's size, density, and number of components and the component's quality. The time it takes to solve a model, the amount of memory needed to solve the problem, how the solution is interpolated across nodes, and the precision of the result are all factors that influence how a problem is solved. Figure 3.14 shows the finite element meshing in 2D of the 8 external electrodes of ECT model. The study was generated to obtain the results such as surface, streamline and contour. Also, the probes were evaluated to get the receivers data. Figure 4 shows an example result obtained for potential and electrical field distribution. Later the sensor reading was used in MATLAB software for obtaining tomograms.

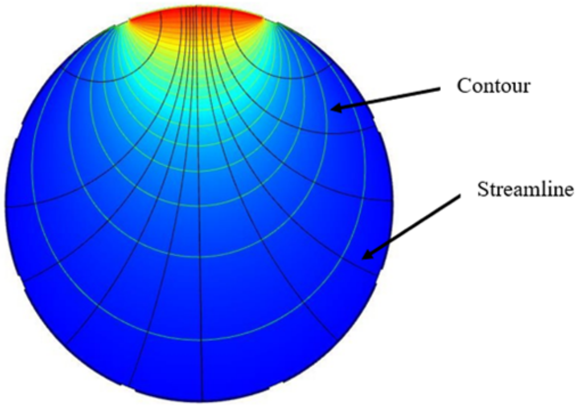

Figure 4. Electric field & potential lines for single excited electrode (channel 1 as excitation electrode)

4. Results and Discussion

After the simulation of three samples of agarwood had been simulated in COMSOL Multiphysics software, the image reconstruction for the samples of agarwood was obtained. To analyze the electrical relative permittivity of agarwood samples, only the value of agarwood sample C was used. This is because the electrical relative permittivity value of agarwood sample C was found to have a greater distortion compared to agarwood sample B and agarwood sample A. The algorithm of Linear Back Projection, LBP algorithm was used to generate the tomograms in MATLAB software of the 9 types of phantoms (agarwood).

Figure 5 shows the tomogram of the single agarwood with 60mm radius, different size with 120mm radius and different position (top right) with 60mm radius. Besides that, Figure 6 shows the tomogram of the phantom A, phantom B and phantom C, while the Figure 7 shows the tomogram of the phantom D, phantom E and phantom F. For all the results, it presented the geometry, contour with streamline, reference image, tomogram and MSSIM index.

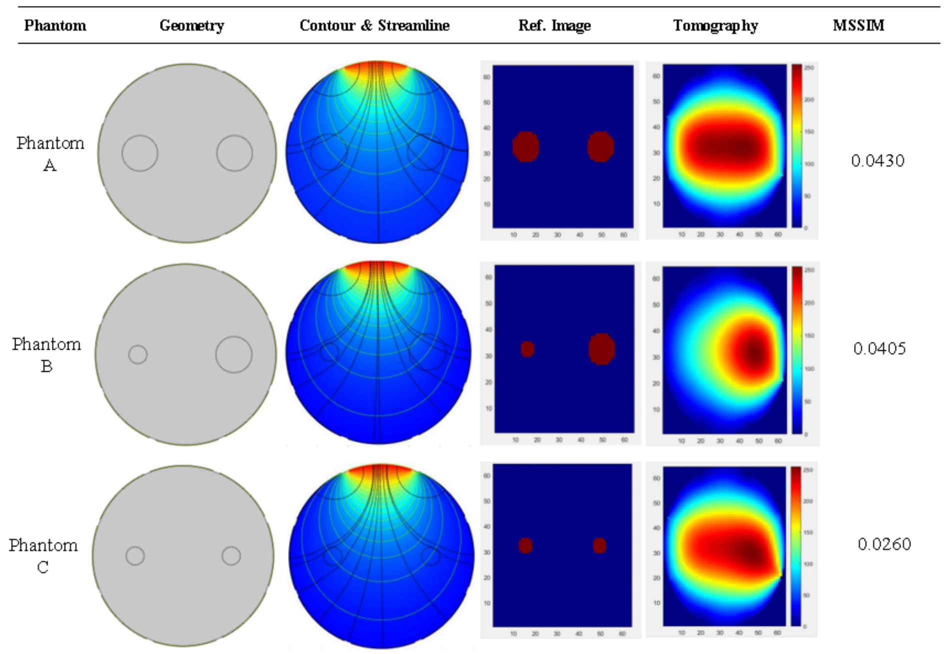

Figure 5. Image reconstruction for different sizes and positions of agarwood

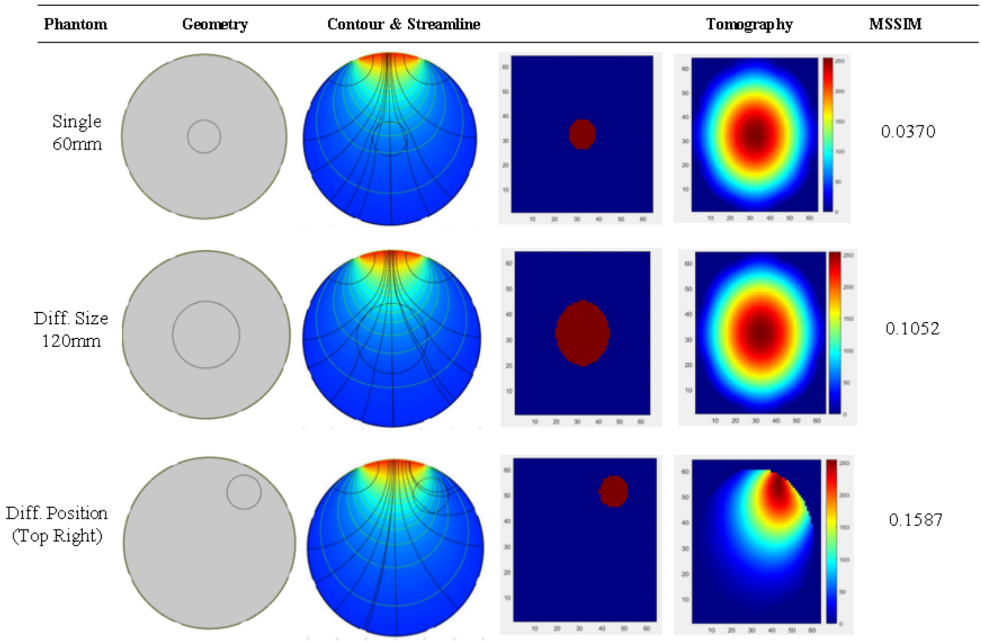

Figure 6. Image reconstruction for different multiple phantoms of agarwood

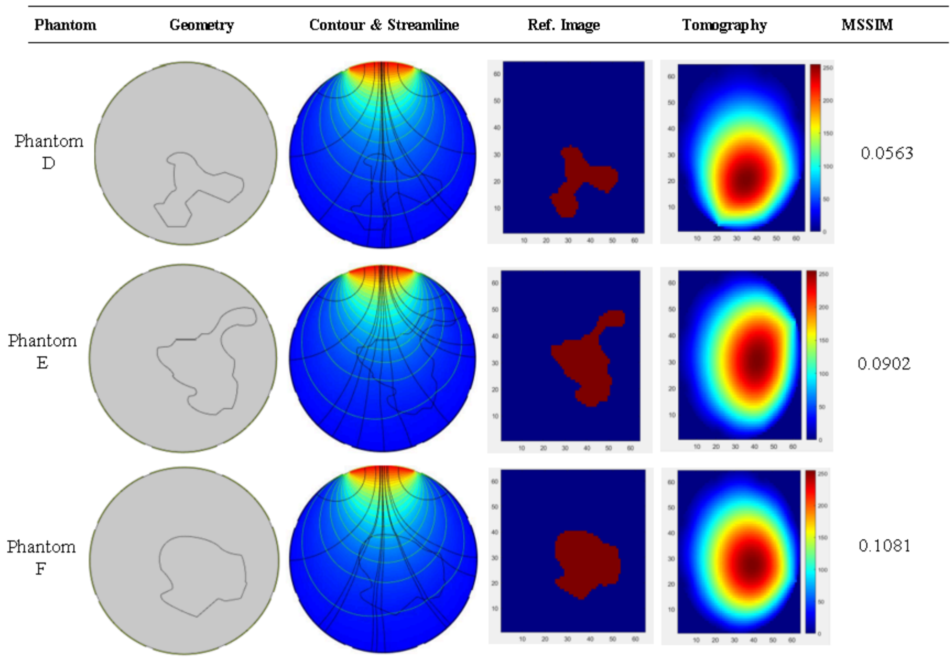

Figure 7. Image reconstruction for different shape of agarwood

Based on Figures 5 to 7, it is evident that all the tomograms exhibit a similar appearance. This similarity can be attributed to the nature of the Linear Back Projection (LBP) method used for image reconstruction, which inherently introduces blurring effects and degrades the image quality[16], [17]. However, a higher Mean Structural Similarity Index (MSSIM) [18]–[20] is observed for larger-sized agarwood, indicating that LBP can generate higher quality tomograms when larger agarwood samples are present.

Furthermore, the results demonstrate that LBP is capable of differentiating between the various tested agarwood samples. The MSSIM value for Phantom D is relatively low because, although it has a larger size, the position of the agarwood is far from the excitation electrode (electrode 1). In contrast, Phantoms E and F show higher MSSIM values compared to Phantom D, as the positions of the agarwood samples are closer to the excitation electrode. The MSSIM value for Phantom C is the lowest due to its location being further away from the electrode and the presence of a small agarwood sample with a radius of 30mm. Therefore, the accuracy of the tomogram in recording the position of agarwood decreases with an increasing distance between the agarwood and the sensor.

In the case of Phantom A, the tomograms appear blurred due to the presence of two larger agarwood samples with a radius of 60mm. As mentioned earlier, this blurriness is a result of the smearing effect caused by the LBP algorithm, which is intensified when multiple agarwood samples are present within the wood, leading to a degradation of tomogram clarity.

5. Conclusions

In summary, the ECT system seems able to detect the agarwood. The image reconstruction using MATLAB software focused solely on the electrical relative permittivity value of agarwood sample C due to its higher distortion compared to agarwood samples A and B. The higher MSSIM index for the result with a different position (top right) indicates that agarwood located near electrode 1 yields better image quality. Conversely, the lowest MSSIM value was observed for phantom C, which had a smaller agarwood sample with a 30mm radius. In future work, it would be beneficial to test the ECT system for agarwood detection in a real-world setting

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