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A REVIEW OF NON-INVASIVE IMAGING: THE OPPORTUNITY OF MAGNETIC INDUCTION TOMOGRAPHY MODALITY IN AGARWOOD INDUSTRY

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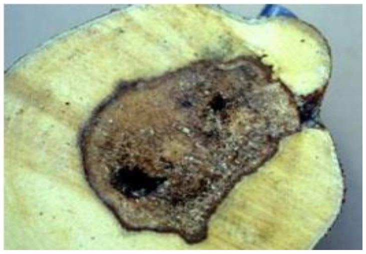
Graphical abstract



Abstract

The needs for non-invasive technique in agarwood industry could enhance and preserve the future of this industry in Malaysia as well as in most of the Asia countries. Normally karas tree which produces agarwood needs at least more than ten years to yield a matured agarwood resin. Thus cutting down the immature trees without pre-assessment on the agarwood content would become a waste of resources. This paper discusses the NDE techniques in wood industry which has the potential to be applied in karas tree for pre-assessment of agarwood volume embedded inside the trees. Finally future research in agarwood imaging using Magnetic Induction Tomography modality is addressed.

Keywords: Agarwood, pre-assessment, magnetic induction tomography, NDE

1.0 INTRODUCTION

Aquilaria malaccensis is a species of plant in the Thymelaeaceae family with large population can be found in Malaysia forest as well as Bangladesh, Bhutan, India, Indonesia, Laos, Myanmar, Philippines and Thailand. This species produces karas or agarwood and also known as agar wood, a highly valuable resinous heartwood for fragrant and perfumes [1]. The resin is produced by the tree in response to infection by a parasitic a dematiaceous (dark-walled) fungus, insect infestation or inoculation [2] as shown in Figure 1. This resin dramatically increases the mass and density of the affected wood, changing its color from pale beige to dark brown or black.

Due to its economic value, this species has been exposed to over exploitation in natural forest habitat by wild agar wood hunter using traditional technique, cutting down the trees without any pre-investigation reliable technique to detect the exist of the resin [3], [4]. Since 1995, *Aquilaria malaccensis* the primary source has been listed as potentially threatened species by the Convention on International Trade in Endangered Species of Wild Fauna and Flora [5].

Figure 1 Cross section shows agarwood formed in a karas tree

To date there are radiations imaging and ultrasonic imaging for wood industry. However in agarwood industry, only ultrasonic imaging modality has been reported but the level is still at research stage. The need for a reliable non-invasive or non-destructive imaging technique in estimating the volume of agarwood resin embedded in a tree is vital before harvesting as it would help the industry to optimize the profit as well as preserve the nature.

2.0 NONDESTRUCTIVE EVALUATION (NDE)

NDE is a wide group of analysis techniques used in science and industry to evaluate the properties of a material, component or system without causing damage [7]. There are several hard field and soft field modalities that may suit the application in agarwood industry.

2.1 Acoustic Tomography

Acoustic technique is a famous known technique which relatively simple and inexpensive [4] deployed in timber for wood quality assessment [5] which utilizes the principle of sound speed. Since acoustic velocity is directly related to density and dynamic modulus of elasticity of wood, acoustic velocity mapping of a cross section could be used as a diagnostic image to detect internal decay in trees [6]. Ultrasonic transducers were arranged surrounding the trunk of the tree and have to be properly attached to the trunk in such that the acoustic energy measurement can be optimized at the receiver.

Li *et al.* [6] used this technique to detect internal decay of hardwood as it is a high value engineered wood products through 2D reconstructed cross section image. Time of flight measurement scheme has been applied with 12 sensors to black cherry log. The developed system indicates that TOF acoustic tomography lacks the sensitivity to low-velocity features of decayed areas and thus has limited capability in detecting early stages of decay in trees.

Indahsuary *et al.* [3] had applied this technique in agarwood detection as shown in Figure 2 by generating sound waves through tapping on one transducer with an electronic hammer whereas the travelled sound waves were received by other transducers.

Figure 2 The set-up of acoustic tomography in agarwood imaging [3]

The developed system was capable in differentiating health and deteriorating wood structure through colour scale representation of high speed and low speed acoustic velocity respectively. The limitation of this system was that it difficult to produce a volumetric image of the agarwood tree as due to its tapped based measurements where many sensors have to be positioned surrounding the trunk to acquire enough data for 3D image reconstruction.

2.2 X-Ray Computed Tomography

X-ray tomography reconstructs the image based on the attenuation of the X-rays [7]. X-ray tomography has been used for scanning of density in internal defects of timber or logs [8] and moisture content of solid wood [9]. Beall [10] did reported a higher energetic range (Co-60: 1.17, 1.33 MeV; Cs-137, 0.66 MeV) need to be used due to mass attenuation coefficient with consideration of wood and moisture combination [9]. The advantage of this modality was a large volume of material can be inspected quickly [11] whereas on the limitation side, the reconstructed image was based on mass distribution with no distinction between wood and water which lead to errors. Since it is contactless technique, it has the possibility of generating volumetric image of the scanned object.

2.3 Magnetic Induction Tomography

Magnetic induction tomography (MIT) is a soft field modality which falls under passive imaging family as electrical impedance tomography (EIT), electrical capacitance tomography (ECT) and magnetostatic tomography [12], [13]. The interest of these modalities are passive electrical properties; conductivity (σ), permittivity (ε) and permeability (μ). However in biological tissue cases, conductivity is dominant compare to other properties [14], [15].

MIT is a contactless and electrodeless technique uses the principle of magnetic induction phenomena in its application. MIT has been explored in the application of biological tissue imaging such as brain imaging [16], [17], liver imaging [18] and lung imaging [19]. In other fields, MIT has been introduced in weapon detection [20], pipeline inspection [21], flow imaging [22-24] non-destructive evaluation application in civil engineering [25-28] as well as the potential in agricultural fields [29].

2.3.1 Fundamental Concept of MIT

MIT system consists of sensors (transmitters and receivers), electronic circuitry, image reconstruction algorithm and controller section [30]. Transmitters generate electromagnetic field signals (primary field) using AC source that travel through region of interest and penetrate the object. Due to the conductivity value of the object, eddy currents are induced within the object itself. These eddy currents then generate its own fields known as secondary fields, which is the field of interest in this research as it contains the information on conductivity distributions within the object. The principle is shown in Figure 3.

The carried information is on the changes of *k*, the complex conductivity of the object which is given by [13]

$$k = \sigma + j\omega\varepsilon \quad (1)$$

where ω is the applied frequency.

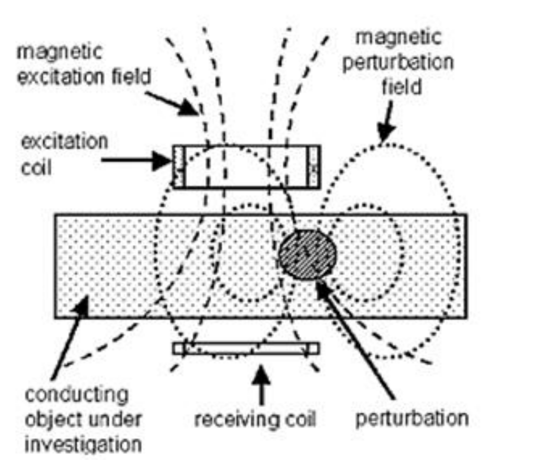


Figure 3 The principle of MIT [12]

The electromagnetic field phenomena in this MIT modality fulfil the Maxwell's equations which are [31]

$$\nabla \times \boldsymbol{E} = -j\omega\boldsymbol{B} \quad 2)$$

$$\nabla \times \boldsymbol{H} = (\sigma + j\omega\varepsilon)\boldsymbol{E} \quad (3)$$

$$\nabla \cdot \boldsymbol{D} = \rho \quad (4)$$

$$\nabla \cdot \boldsymbol{B} = 0 \quad (5)$$

Equation (2) is Faraday's Law, equation (3) is Ampere's Law, equation (4) is Gauss's Law and equation (5) stated that there is no magnetic charges exist in a region.

2.3.2 Advantages of MIT Modality

MIT becomes the choice among other modalities because of its contactless and electrodeless measurement scheme which offers no electrode-skin interface mechanism [32], [33], [34]. The existing of this interface provides high possibility of errors in the measurement due to incorrect electrode position and no proper contact between electrode and skin.

It is a robust imaging technique with respect to jumps in conductivity coefficient [35][36] and the robustness can be improved with the optimization design of the parameters of the non-magnetic shield [37].

MIT applies non-ionizing radiation technique [38-40] which most of the people currently searching for. Ionizing radiation issues have become among major reason the researchers start to divert to safer imaging modalities. So far, MIT modality applies input signal ranging from kHz to several MHz. Frequency of kHz range usually applies in high conductivity material (metal) imaging [41],[42] whereas frequency up to several MHz range is for low conductivity imaging (i.e biological tissues) [34],[43],[44].

2.3.3 Challenges of MIT Modality

MIT is a soft field modality which produces low resolution imaging [20],[45],[46] due to solving the nonlinear nature of electromagnetic field using linear image reconstruction algorithm [43]. This approximation works well for low contrast imaging but needs nonlinear techniques for high resolution imaging [47].

MIT is sensitive to noise [48],[49], thus electromagnetic screen is needed to cover the region of interest as well as the circuit from the noise interruption which causes errors in the measurement [50],[51].

2.3.4 MIT Measurement Schemes

In the application of high conductivity imaging (i.e metal), magnitude base measurement scheme can be implemented as the signal is strong enough at the receiving coil in relative to the noise due to high secondary field of high conductivity material. Peak detector is among the reported technique for this scheme [30].

In low conductivity measurement (i.e biological tissue), secondary field due to eddy current is very low and normally mixed with noise signals. Thus magnitude base measurement is not suitable. To solve this issue, phase shift measurement has been reported as the solution. In this scheme, primary field (the field generated by the transmitter) will be the reference to compare delay time for secondary field to arrive at the receiver. The higher the conductivity of the material the longer time will take for the secondary signal to travel and reach the receiver [50].

3.0 CONCLUSION

Non-invasive imaging offers a great opportunity in agarwood industry as well as the potential to be applied in other wood industries. These techniques provide solutions to the losses of natural populations while optimize the profit of the industry itself. From the literature, MIT is not yet explored in agarwood industry even theoretically MIT has been found has advantages and capability in relative to the current radiation base imaging and ultrasonic imaging due to its electrodeless, contactless and free from ionizing radiation issue.

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