DEVELOPMENT OF FRUIT MATURITY TESTING SYSTEM USING RF PROPERTIES

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To my lovely mother and father, my love and my family

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ABSTRACT

Microwaves are electromagnetic waves with wavelengths shorter than one meter and longer than one millimeter, or frequencies between 300 megahertz and 300 gigahertz. Microwave usually associated with Radio Frequency. Microwave measurements and the dielectric properties of materials are finding increasing application, as new electro technology is adapted for use in agriculture and food processing industries. In the agricultural industries, determine the maturity of fruit will be taken much more time. This project is about microwave free-space measurement by using 2 waveguide antennas (Horn Antenna) as transmitter and receiver operating in frequency range of 2.1 – 3.0 GHz to determine the insertion loss (S21) after passing through banana which can be calculated in term of Complex Permittivity. The results from the observation show that this technique can determine fruit maturity base on the dielectric changing in the fruit sample.

PEMBANGUNAN SISTEM PENGENALPASTIAN TAHAP KEMATANGAN BUAH DENGAN MENGGUNAKAN KAEDAH RADIO FREKUENSI

ABSTRAK

Gelombang mikro adalah gelombang elektromagnetik dengan panjang gelombang lebih pendek daripada satu meter dan lebih panjang daripada satu millimeter, atau frekuensi diantara 300 Megahertz hingga 300 Gigahertz. Gelombang mikro ini sering dikaitkan dengan Radio Frekuensi. Sukatan gelombang mikro dan dwi elektrik sesuatu bahan dilihat akan bertambah aplikasinya sebagai satu teknologi elektro baru yang boleh disesuaikan untuk kegunaan industri memproses makanan dan pertanian. Di dalam industri pertanian, penentuan kadar kematangan buah memerlukan masa yang lebih lama. Kertas kerja ini menghuraikan tentang teknik pengiraan gelombang mikro dalam ruang udara bebas dengan menggunakan 2 gelombang terarah antenna (Antena Horn) sebagai pemancar dan penerima frekuensi yang jaraknya diantara 2.1 – 3.0 Gigahertz untuk menentukan kehilangan penyusupan (S21) setelah melepasi sampel buah yang mana boleh dikira secara Kebolehtelusan Kompleks. Hasil daripada pemerhatian menunjukkan teknik ini boleh menentukan kematangan buah berdasarkan perubahan dielektrik di dalam sampel buah tersebut.

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LIST OF SYMBOL AND ABBREVIATION

ε_r	Complex relative permittivity
μ_r	Complex relative permeability
$tan\delta$	Tangent loss
f	Frequency
c	Speed of light
λ	Wavelength
λ_g	Guided wavelength
λ_o	Free-space wavelength
λ_c	Cutoff wavelength
ε'	Dielectric constant
ε''	Dielectric loss factor
S_{11}	Transmission power
S_{21}	Reflection power
X	X parameter
Γ	Reflection coefficient
T	Transmission coefficient
L	Length of material

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CHAPTER 1

INTRODUCTION

1.1 Background History

Dielectric constant is the electrical properties of fundamental importance in microwave processing of foods and fruits. It determines how materials interact with electric fields such as those of high-frequency and microwave electromagnetic energy. As a new electro-technology is adapted due to increasing of microwave and dielectric properties in agriculture, it has been associated with the design of electrical equipment. Various dielectrics used for insulating conductors and other components in electrical equipment.

Dielectric properties have been applied in many sectors including agriculture. These have included the sensing of moisture in grain and seed [1], non-chemical postharvest insect control in fruits [2] and seed and soil treatment [3].

The concept of permittivity measurements was based on dc electrical resistance to determine grain moisture content. From the study on polar dielectrics, a non-linear increase in resistance of the grain as temperature decreased gave useful observations but there is no quantitative data was found. Later, ac measurements commonly employed to measure the change in capacitance and suitable sample holding capacitors were developed.

Grain moisture measurement based on dielectric properties data became the most prominent agricultural application. The development of this encourage to a new technique which contributed to several applications of radio frequency dielectric heating. For the last 15 years, the concept of permittivity measurement has been extended and applied to various cultural and food. The main purpose of this project is to study Radio Frequency method of dielectric properties measurement between frequency range of 2.1GHz to 3.0GHz and the procedure to get the value of dielectric by using the microwave reflection and transmission theory.

1.2 Objective

Objectives of this development of a non-destructive fruit maturity testing system utilizing radio frequency properties are:

i. To determine the dielectric of fruit using radio frequency.
ii. To develop Graphic User Interface (GUI) using VEE software that will automatically calculated the dielectric of fruit and shows the level of fruit maturity.
iii. To observe the relation between dielectric with the level of fruit maturity.

1.3 Scope of Study

Scope of this study is to determine the level of fruit maturity by using Radio Frequency. In this project, microwave is used as the Radio Frequency method. The antenna will transmit microwave through the fruit and receive back the microwave to the other antenna as a receiver. As Horn Antenna has the transmitting and receiving properties, so it is suitable to use it for this project. This antenna will transmit microwave through the fruit and receive back the microwave to the other antenna as a receiver. The collecting data which is S11 (reflection) and S21 (transmission) will be calculated and dielectric of fruits will be determine. Scope of study is also limit to determine the easier procedure to get the dielectric of fruit. The determination of dielectric is by using the free space method and Nicolson-Ross-Weir (NRW) procedure.

1.4 Problem Statement

In industries of fruits, human energy used to distribute the fruits following level of maturity. This will cause the inconsistent result during detach process. The difficulty to know the level of fruit maturity may result in the fruit being harvested too early before maturity or over maturity, resulting in the fruit not ripening or ripening too early when delivered to the distributor. A technique to determine the maturity of the fruit will overcome the said problem.

CHAPTER 2

LITERATURE REVIEW

2.1 Dielectric Properties Measurement in Agriculture

Dielectric properties of materials are electrical properties that determine how materials interact with electric fields such as those of high-frequency and microwave electromagnetic energy. Therefore, the dielectric properties of materials determine how rapidly they will heat in microwave ovens and lower radio-frequency dielectric heating equipment. Dielectric properties are also important in low power applications, such as their use in the rapid measurement of moisture content in grain and other commodities. Electronic moisture meters use radio-frequency electric fields to sense moisture content in products such as grain, because the dielectric properties are highly correlated with the moisture content of the grain.

The use of dielectric properties of agricultural products for sensing moisture in grain and seed and their application in radio-frequency and microwave dielectric heating is discussed briefly. Values for the dielectric properties of a number of products, including grain and seed, fruits and vegetables, and poultry products, are presented graphically to show the dependence of these properties on frequency, moisture content, and temperature. The potential for using the dielectric properties to sense quality factors other than moisture content is also considered [5].

The dielectric properties of 15 vegetables and fruits were measured at 2450MHz from 5 to 130 °C. Equations were developed as a function of temperature, ash, and either moisture content or water activity, and compared to literature equations. Dielectric constant of vegetables and fruits decreased with temperature and ash content. However, ash was not a factor in the equations produced separately for fruits. Dielectric loss factor changed quadrically with increasing temperature: first decreasing and then increasing. This transition temperature decreased with ash content. Ash increased the dielectric loss factor. Garlic and potato gave unusual results, which could be explained by the behavior of solutions of inulin and potato starch, respectively [6].

Dielectric properties of tomato slices are highly useful for predicting the heating rates and behavior of the materials when subjected to high frequency electromagnetic waves. Dielectric properties of tomato slice (6 mm) at different moisture contents such 10, 30, 50 and 70% (water based) were determined by using microwave spectroscopy. The corresponding dielectric properties like dielectric constant (e') and dielectric loss (e.) were observed. The result showed that both dielectric constant (77 to 7.2) and dielectric loss (48 to 3.4) decreased with increase in frequency from 200 MHz to 200 GHz. Drying of tomato slices were carried out at 50, 60, 70oC by using two methods namely microwave assisted vacuum dryer and microwave assisted hot air dryer at the selected temperatures. From the study, it was found that the time taken for drying of tomato slice in microwave assisted vacuum was lower (150, 100 and 70 min) when compared to microwave assisted hot air drying at 50, 60 and 70oC, respectively [7].

New nondestructive techniques for sensing quality measurement of many fruits and vegetables, such as apples, peaches, pears, melons and potatoes that has been stored before consumption would be helpful to producers, handlers and consumers. Subjective quality standards for many products tend to be highly arbitrary, different for individual consumers and for sellers and buyers, and often subject to supply and demand [8]. Sensors for microwave (MW) technology show the advantage of being non-destructive and low-cost. The measurements are based on the interaction of an electromagnetic wave at a known frequency such as radio frequency (RF) and MW range, from 10–20MHz to 20GHz with a sample, where the reflection and the phase shift, and therefore the corresponding dielectric properties, can be determined. Permeability and permittivity are two important properties of material that determine its electromagnetic characteristics.

Research By	About	Frequency Used	Result
Dunlap and Makower (1945)	Dielectric properties for carrots	18 kHz to 5 MHz	Higher frequencies were most suitable for moisture determinations in food products
Shaw and Galvin (1949)	Dielectric properties of potato, carrot, apple, and peach tissue	1 to 40 MHz	Useful data on the temperature dependence in fruits and vegetables between 100kHz - 20MHz
Pace, Westphal and S.A. Goldblith. (1968)	Dielectric properties of raw potato	300 to 3000 MHz	Dielectric properties dropped appreciably with increasing frequency
Thompson, D.R. and G.L. Zachariah.(1971)	Dielectric properties of apples	300 to 900 MHz	Dielectric properties vary with maturity, dropping appreciably in the process of aging
Stuchly, M.A. and S.S. Stuchly. (1980)	Effect of moisture content on the dielectric properties of granular solids	9.4 GHz	Temperature dependence was not seen for dried solids but increased dramatically at

			higher moisture contents
Pace et al. (1968)	Potential for microwave finish drying of potato chips	1.0 to 3.0 GHz	Energy absorption increased at higher moisture contents
Bengtsson and Risman (1971)	Dielectric properties for foods at 2.8 GHz and temperatures from -20 to 60°C	2.8 GHz	Wide variation in dielectric behavior due to differences in chemical composition, physical state, and temperature

Table 2.1: Summary of the previous research on dielectric properties

In quality determination of fruit, Ketsa and Dangkanit presented the relation between the maturity and chemical compound of fruit which is a destructive technique [12]. A nondestructive ultrasonic measurement system was developed for the assessment of some transmission parameters which might have quantitative relations with the maturity, firmness and other quality-related properties of fruits [9]. A system using impulse impedance technique was developed to nondestructively determine fruits maturity [10]. Slaughter used near infrared to determine chemical structure inside tomato and peach [11].

2.2 Measurement Technique in Radio Frequency

Measurement of dielectric properties involves measurements of the complex relative permittivity (ε_r) and complex relative permeability (μ_r) of the materials. A complex dielectric permittivity consists of a real part and an imaginary part. The real part of the complex permittivity, also known as dielectric constant is a measure of the amount of energy from an external electrical field stored in the material. The imaginary part is zero for lossless materials and is also known as loss factor. It is a measure of the amount of energy loss from the material due to an external electric field. The term $tan\delta$ is called loss tangent and it represents the ratio of the imaginary part to the real part of the complex permittivity. The loss tangent is also called by terms such as tangent loss, dissipation factor or loss factor.

The complex permeability also consists of a real part which represents the amount energy from an external magnetic field stored in the material whereas the imaginary part represents the amount of energy dissipated due to the magnetic field. Measurement on the complex permeability is only applicable to magnetic materials. Most materials are nonmagnetic and thus, the permeability is very near to the permeability of free space. There are many techniques developed for measuring the complex permittivity and permeability and each technique is limited to specific frequencies, materials, applications etc. by its own constraint. There are four techniques which are:

i) Transmission/reflection line technique.

- Transmission/Reflection line technique is a popular broadband measurement technique. In the technique, only the fundamental waveguide mode (Transverse Electromagnetic (TEM) mode in coaxial line and Transverse Electric (TE) mode in waveguides) is assumed to propagate.

ii) Open ended coaxial probe technique.

- The Open-ended co-axial probe technique is a non-destructive technique and the technique assumes only the TEM or TE mode is propagating.

iii) Free space technique.

- The free space technique is for broadband applications and assumed only the TEM propagation mode.

iv) Resonant technique.

- The resonant technique provides high accuracies and assumes the TE or Transverse Magnetic(TM) propagation mode.

Measurement Techniques	Materials	S-Parameters	Dielectric properties
Transmission/Reflection Line	Coaxial line, waveguides	S_{11}, S_{21}	ε_r, μ_r
Open-ended coaxial probe	Liquids, biological specimen, semi-solids	S_{11}	ε_r
Free space	High temperature, material, large flat solid, gas, hot liquids	S_{11},S_{21}	ε_r, μ_r
Resonant Technique (Cavity)	Rod shaped solid materials, waveguides, liquids	Frequencies, Q-factors	ε_r, μ_r

Table 2.2: Comparison between the measurement techniques

By using transmission line, coaxial line and waveguides are commonly used to measure samples with medium loss to high loss. It also can be used to determine both permittivity and permeability of the material under test. However, this transmission line measurement is not so accurate since it is limited by the air gap effects. Open-ended coaxial probe does not need machining of sample, so it easy for sample preparation. The dielectric properties of large number of samples can be measured in short time after the calibration process. Same as using transmission line, it will get affected by air gap for measurement on specimen. For high frequency measurement, free space method is the best way to measure the dielectric of materials. This free space method is kind of non destructive method. The disadvantages of free space method need large area for material under test and will get multiple reflections between antenna ad samples.