UNIVERSITI PUTRA MALAYSIA

CHARACTERIZATION OF OIL PALM FRUITLETS USING ARTIFICIAL NEURAL NETWORK

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By

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Accurate data of the dielectric properties of oil palm fruitlets and the development of appropriate models are central to the quest of quality sensing and characterization, and Artificial Neural Network (ANN) and Adaptive Neurofuzzy Inference Systems (ANFIS) are becoming increasingly relevant for this purpose owing to their excellent pattern matching and generalization ability. In this study, a Layer Sensitivity-Based Artificial Neural Network (LSB_ANN) and a Multi-Adaptive Neurofuzzy Inference System (Multi-ANFIS) were designed to characterize oil palm fruitlets and to model the dielectric phenomena of microwave interacting with oil palm fruitlets within the frequency range of 2-4GHz. The LSB_ANN has a unique weight update mechanism which employs network layer input-output sensitivity analysis. The inputs of the networks are the frequency, the magnitude of the reflection coefficient and the phase of the reflection coefficient while the outputs are the dielectric constant, the loss factor and the oil content. The training data for the models were obtained from dielectric and moisture content measurements and the obtained data were fitted into the quasi-static wave Equations and optimized using MATLAB complex root finding technique to obtain the normalized conductance, susceptance and the complex permittivity of the fruitlets. To further validate the generalization accuracy of the LSB_ANN, its performance was compared with that of a Multi-ANFIS network as well as those of three different ANN training algorithms: Levenberg Marquardt (LM) algorithm, Resilient Backpropagation (RP) algorithm and Gradient Descent with Adaptive learning rate (GDA). Having a testing Variance-For (VAF) of 97.81 and Root Mean Square Error of 3.97, the LSB_ANN was found to possess a better post training generalization ability than the LM, RP and GDA algorithms which had VAF of 93.57, 96.26 and 94.09 respectively, and RMSE of 4.14, 4.38, and 7.98 respectively. The results also showed that contrary to the

widely reported gap between the accuracy of the LM algorithm and other feed forward neural network training algorithms, the RP trained network performed as good as that of the LM algorithm for the range of data considered. A user friendly neural network based Graphical User Interface (GUI) was designed suitable for rapid determination of the dielectric constant and percentage oil content of oil palm fruitlets from measured magnitude and phase of reflection coefficient within a frequency range of 2-4GHz.

Abstrak tesis yang dibentangkan kepada Senat Universiti Putra Malaysia bagi memenuhi keperluan ijazah Master Sains

PENCIRIAN BIJI KELAPA SAWIT MELALUI PENGUNAAN RANGKAIAN NEURAL BUATAN

Oleh

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Data tentang sifat-sifat dielektrik biji kelapa sawit yang tepat dan pembangunan model yang sesuai adalah asas kepada usaha penderiaan yang berkualiti dan pencirian bahan. Rangkaian Neural Buatan (ANN) dan Sistem Taabir Neurofuzzy (ANFIS) kian bertambah penting atasa potensi kedua-dua sistem ini dalam pengetaraan corak dan generalisasi. Satu Rangkaian Neural Buatan Berasaskan Kepekaan Lapisan (LSB_ANN) dan Sistem Taabir Neurofuzzy Berbilang-Suai (Multi-ANFIS) telah direkabentuk demi kajian ini, bagi tujuan mencirikan biji kelapa sawit serta membina model fenomena dielektrik gelombang mikro yang berinteraksi dengan biji-biji tersebut di dalam julat frekuensi 2-4GHz. Sistem LSB_ANN mempunyai mekanisme yang unik, iaitu mekanisme pembaharuan berat. Mekasime ini menjalankan Analisa Kepekaan Input-Output Lapisan Rangkaian. Input-input kepada rangkaian tersebut terdiri daripada frekuensi, magnitud pekali pantulan dan fasa pekali pantulan, manakala output-output terdiri daripada pekali dielektrik, faktor kehilangan, serta kandungan minyak. Data latihan model-model tersebut diperoleh melalui sukatan kandungan air dan sukatan. Berikutannya, data yang diperoleh telah dimasukkan ke dalam persamaan gelombang quasi-statik dan dioptimumkan dengan teknik carian akar kompleks MATLAB. Hasilnya ialah kebertelusan kompleks biji kelapa sawit, konduksi piawai, dan susceptance. Prestasi LSB_ANN dibandingkan dengan rangkaian MULTI_ANFIS serta rangkaian yang berasaskan algoritma latihan ANN yang lain bagi mengesahkan lagi kejituan generalisasi LSB_ANN: algoritma Levenberg Marquardt (LM), algoritma *Resilient Backpropagation* (RB), dan *Gradient Descent with Adaptive learning rate* (GDA).
Nilai Ujian *Variance-For* (VAF) iaitu 97.81 dan nilai ujian *Root Mean Square Error* (RMSE) iaitu 3.97 membuktikan bahawa LSB_ANN ada kebolehan generalisasi pasca-latihan yang lebih baik berbanding algoritma LM, RP dan

GDA. Algoritma-alogoritma tersebut mempunyai nilai VAF sebanyak 93.57, 96.26, dan 94.09 serta nilai RMSE sebanyak 4.14, 4.38, dan 7.98 masing-masing. Keputusan ini bertentangan dengan tanggapan am mengenai jurang besar di antara kejituan algoritma LM dan algoritma latihan rangkaian neural suapdepan yang lain, di mana rangkaian RP terlatih didapati mempunyai prestasi yang sama dengan algoritma LM bagi julat data tersebut. Lantaran itu, satu *Graphical User Interface* (GUI) berdasarkan rangkaian neural yang pro-pengguna telah direkabentuk agar menentukan pekali dielektrik serta peratus kandungan minyak biji kelapa sawit, berasakan magnitud dan fasa pekali pantulan 2-4GHz dengan cepat.

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This thesis was submitted to the Senate of Universiti Putra Malaysia and has been accepted as fulfillment of the requirement for the degree of Master of Science. The members of the Supervisory Committee were as follows:

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DECLARATION

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LIST OF SYMBOLS

ε	Complex permittivity
$\varepsilon^{'}$	Dielectric constant
$\varepsilon^{''}$	Dielectric loss factor
$E(x)$	Electric field as a function of horizontal distance x.
λ_0	Wavelength in vacuum
E_0	Electric field intensity
d_p	Penetration depth
c	Speed of light
f	Frequency (GHz)
Γ	Reflection coefficient
$V-$	Reflected voltage
$V+$	Incident voltage
A_e	Empirical coefficient
Γ'	Real part of the reflection coefficient
Γ''	Imaginary part of the reflection coefficient
Y_0	Characteristic admittance
Γ_{Actual}	Measured reflection coefficient
C_T	Aperture coefficient
ω	Angular frequency
ε_r	Relative permittivity
b	Radius of the outer conductor

a	Radius of the inner conductor
μ_0	Permeability of free space
ε_c	Dielectric constant of coaxial sensor material
ε_0	Permittivity of free space
L	Length of virtual line
D	Length of physical line
Y_L	Aperture admittance
Y_d	Characteristic admittance
Y_E	Terminating admittance
β_d	Propagation constant
Y	Admittance
ϕ	Azimuthal angle of magnetic field component
ρ	Radial angle of the electric field component
G	Aperture conductance
B	Aperture susceptance
Si	Sine integral
J_0	Bessel function of order zero
k_0	Free space propagation constant
$\tilde{Y}_L$	Normalized admittance
Q_0	Quality factor of the of empty cavity
Q_1	Quality factor of the of loaded cavity

V_c	Cavity volume
V_s	Sample volume
f_0	Resonant frequency of empty cavity
f_1	Resonant cavity of loaded cavity
T	Total number of available training vectors
C_f	Absolute moment of Fourier magnitude distribution
N_h	Minimum number of hidden neurons
M_c	Percentage moisture content
O_c	Percentage oil content
S'_m	Mass of sample after drying
S_m	Mass of sample before drying
$J_v(x)$	Bessel function of order v
k_1	Wave number of the inner conductor
k_2	Wave number of the outer conductor
f_h	Hidden layer activation function
w	Connection weight
P	Input
b_1	bias
y_{ij}	Network output
N	Number of inputs
J	Number of training datapoints
I	Number of outputs

f_i^{-1}	Inverted activation function
E	Cost function
E'	Cost function due to first layer
E''	Cost function due to second layer
var	Variance
P_i	Actual input data
P_{max}	Maximum input
P_{min}	Minimum input
${P^t}_{max}$	Maximum target
${P^t}_{min}$	Minimum target
$J(w)$	Jacobian matrix
$\boldsymbol{e}$	Error matrix
η^-	Step factor
Δ_{ij}	Weight update value
α	Learning rate
τ	Learning step size
σ	Membership function parameter
H	Magnetic field
E	Electric field
θ	Cylindrical coordinate

LIST OF ABBREVIATIONS

M-File	MATLAB File
GUIDE	Graphical User Interface Development Environment
EM	Electromagnetic wave
RP	Resilient Backpropagation algorithm
LM	Levenberg-Marquardt
GDA	Gradient Descent with Adaptive Learning Rate
GUI	Graphical User Interface
RMSE	Root Mean Square Error
CMD	Coefficient of Multiple Determination
VAF	Variance Account-For
SSE	Sum of Squared Error
LSB_ANN	Layer sensitivity based Artificial Neural Network
ANFIS	Adaptive Neuro-Fuzzy Inference System
R	Regression coefficient

CHAPTER ONE

INTRODUCTION

1.1 Introduction

This thesis was designed to characterize oil palm fruitlets using a combination of microwave technique and intelligent softcomputing techniques. In order to achieve this, several neural network algorithms, network types and network architectures were compared including Adaptive Neurofuzzy Inference System (ANFIS). This chapter therefore introduces the concept and general background of the work, it also specifies the identified problem statements as well as the aims and objectives of the study. The scope and significance of the study are also presented.

1.2 Background

The oil palm is a perennial plant of the *arecaceae* family commonly grown in the tropical region of the world and its fruit is the most common source of edible oil with an annual yield of 4.2 tonnes per hectare and global annual yield of 45 million tonnes (shown in Figure 1.1) (Ong *et al.*, 2011). In recent years, oil palm has found more extensive use in oleochemicals, biofuels and numerous processed oil products, a study on a more accurate means of characterizing this productive fruit is therefore necessary.

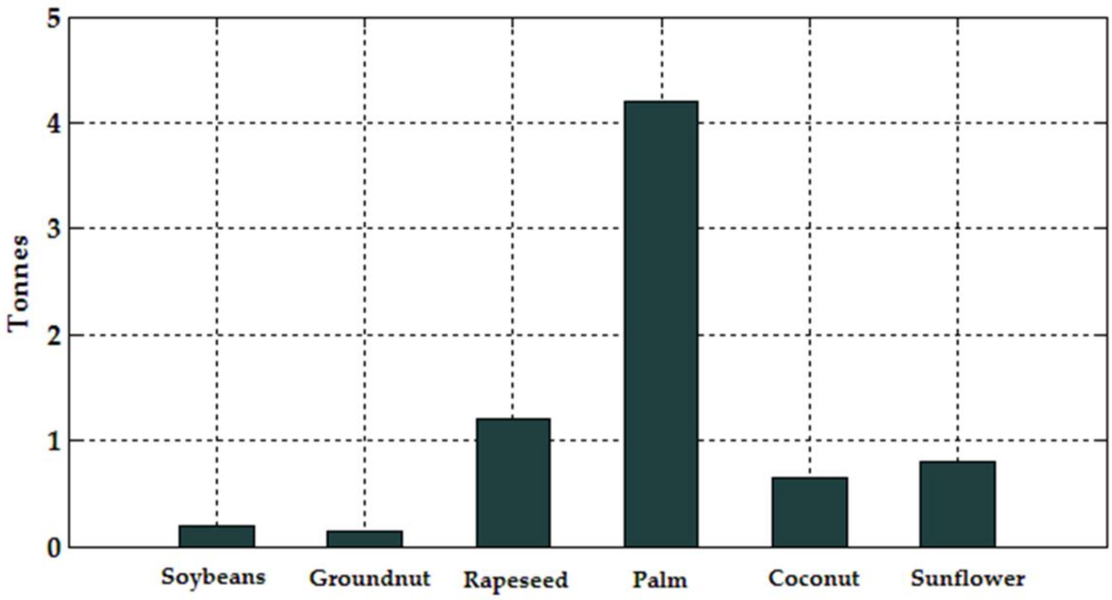

Figure 1.1 Annual Yield of Selected Vegetable Oils Per Hectare (Tan et al., 2009)

1.2.1 The Oil Palm – Constituents, Uses and Measurement Techniques

The oil palm fruit structure is made up of fiber and hundreds of oil rich fruitlets, each fruitlet consist of a fleshy mesocarp, a hard shell and a core of palm kernel. Due to recent research successes in the biotechnology industry, oil palm and its products are finding wider usage (other than the present huge collection of edible products) in biodiesel and fiberboard production (Tan *et al.*, 2009). These uses and many more applications have made progressive researches on oil palm quality improvement a journey worth taking.

On the sensing and determination of the quality of oil palm fruitlets in the last decade, the central attention of the researches has taken a shift from the more traditional destructive evaluation methods which involve crushing and grinding of the samples, to nondestructive evaluation. In view of this, several methods have been applied for grading the quality and maturity of oil palm fruits and fruitlets nondestructively (You et al., 2010) and one of the more recent of these techniques is the inductive concept frequency technique (Harun *et al.*, 2013).

The knowledge of the dielectric properties of a material is of ultimate importance in the quest for accurate sensing and characterization. Several electronic and microwave techniques used in nondestructive evaluation therefore involves the extraction of the complex permittivity information. For example, a maturity and quality scale for peaches was proposed (Stuart *et al.*, 2008) based on the values of the dielectric constants and loss factor obtained from rigorous laboratory microwave measurement by coaxial sensor technique. This approach has been extended and combined with other methods such as dry oven method for the determination of crispness and ripeness (Soltani *et al.*, 2011), bacterial content, structure, concentration, moisture content, and bulk density of organic materials (Perez, 2012); Gao *et al.*, 2012). Similar works have also been done for oil palm fruits in which the determination of dielectric properties have been central to the quest of nondestructive measurement and grading (You, 2006; Abbas *et al.*, 2005).

1.2.2 Softcomputing Techniques for Characterization

Therefore, in order to further understand the details of the dielectric behaviour of oil palm fruitlets in the presence of electromagnetic field, accurate models need to be developed. To this extent, artificial intelligent models and soft computing techniques can be helpful. These include Artificial Neural Networks – a connection of processing elements that mimics biological learning, Fuzzy Logic Systems – a logic system which uses membership functions that vary over a range of total inclusion and complete exclusion, Genetic Algorithm (GA) – which employs the techniques similar to biological concept of mutation, crossover and offspring, Adaptive Neuro-Fuzzy

Inference System (ANFIS) – which combines the excellent learning capacity of ANNs with Fuzzy Inference System (FIS), and Swamp Computing. Generally, these models are relatively easier to implement when compared against the more traditional mathematical models because they are regarded as black or gray models; requiring only little or no *priori* knowledge of the system being modeled.

Artificial Neural Networks (ANNs) have particularly been used successfully because of their desirable qualities of being fast, ability to model nonlinear systems and their excellent predictive abilities. There are however numerous training algorithms, network architectures and neural configurations that can distinguish and characterize an ANN for a particular application. These depend on the structure of the data that describes the problem domain, the available processing resources, time, and the minimum expected performance of the network.

In order to improve the generalization accuracy of neural networks, researchers are concentrating efforts on layer-by-layer optimization procedures and Layer Sensitivity Based ANN (LSB_ANN) is one of such in which the network learns and adapts its weights by analyzing the sensitivity function of its weight with respect to the input-output patterns.

In summary, with the increasing global demand for edible oil and other oil palm products, the unique advantages offered by quality sensing through artificial intelligent techniques must be readily usurped to stand as a handy, fast and intelligent tool to help researchers, quality control engineers as well as production managers in making rapid but well informed decisions concerning the quality of oil palm fruitlets.

1.3 Problem Statement

Information on the dielectric properties of oil palm fruitlets and their responses to electromagnetic energy is of great interest, especially for the purpose of nondestructive sensing, grading and characterization. The procedure involved in successfully obtaining this information through open-ended coaxial probe technique is in stages. Firstly, microwave propagating through the line at desired frequency range is made incident on the fruitlet, this results in reflection at the probe-sample interface. The observed reflection and transmission parameters are then fitted into appropriate models and dry oven moisture data to obtain the dielectric properties of the fruitlets.

Unfortunately, the procedure of extracting the desired dielectric properties from these reflection parameters by inverse solution is quite cumbersome; requiring intense computation of triple integrals, series expansions and optimization due to the complexity of the analytical probe admittance equations involved. This requirement substantially increases the time interval between the end of measurements and the instance of obtaining the targeted dielectric values. Furthermore, questions have been raised over the individual relevance of the phase and the magnitude of the reflection coefficient in determination of the dielectric constants of oil palm fruits from open-ended coaxial sensor measurement, the development of a model which considers both variables is therefore necessary.

This thesis therefore attempts to proffer an Artificial Neural Network (ANN) model for these processes in order to solve the problem of computational requirements and eliminate the need for repeated stages of mathematical operations and optimization in the quest of obtaining dielectric properties and oil contents from measured reflection coefficients of the oil palm fruitlets.

1.4 Aim and Objectives

The aim of this thesis is to design and implement an artificial neural network for intelligent characterization of oil palm fruitlets. In order to achieve this, the following objectives are highlighted:

(1) To derive the complex permittivities of oil palm fruitlet mesocarp within a frequency range of 2-4GHz from quasi static admittance analytical model.

(2) To compare the accuracy of the performances of Artificial Neural Network and its associated algorithms with the accuracy of Adaptive Neurofuzzy Inference System for the characterization of oil palm fruitlets.

(3) To design a Graphical User Interface (GUI) from observed results of the open-ended coaxial probe microwave measurements for the grading of the quality of oil palm fruitlets.

1.5 Research Scope and Limitation

There is a wide range of microwave techniques that can be successfully employed in material sensing: free-space measurement technique, open-ended coaxial probe (OCP) technique, and resonant cavity technique. The methodology for this work is however limited to the open-ended coaxial probe technique and the range of frequency considered is 2-4GHz. There are also a number of applicable extraction techniques available for use from literatures; however this work focuses mainly on the improved analytical approach which has recorded good success in the area of dielectric measurement in recent years. It is also worthy of note that the material under test for this thesis is the oil palm fruitlet (which is a single member of the aggregate oil palm fruit bunch). Additionally, the samples used in this work are fresh ripe oil palm fruitlets which were collected from the University farm within 48 hours of harvest. The fruitlets are all ripe and matured. This thesis involves the training of softcomputing models with different algorithms to predict the quality of oil palm fruitlets.

1.6 Layout of Thesis

Chapter one of this thesis contains sub-sections that provide a quick insight into the work as a whole. These include the background, the problem statement, and the research objectives. The scope and limitations in terms of methods, equipment, and frequency usage are also included in this chapter.

A review of relevant previous works in the line of this thesis is presented in chapter two, including current trends and overview of the important concepts for this work. Overviews of theories, backgrounds and applications of Artificial Neural Networks (ANNs), Adaptive Neurofuzzy Inference System (ANFIS), microwave measurement techniques, complex permittivity extraction, and the admittance model are particularly presented.

The steps and procedures employed in obtaining the results in different aspects of this work are described in chapter three. Here, the details of the models and their training algorithms, the basic architecture and neural configuration of the model frameworks including the input-output specifications are presented. The procedure and mathematical basis for extraction of the dielectric constants for the oil palm from open-ended coaxial probe microwave measurement technique are presented.

Chapter four contains the results obtained in the course of this work and the discussion of the results in relation to the available knowledge-base in soft computing and dielectric measurement.

In chapter five, the conclusion of the whole work and a summary of the results are presented, including recommendations and major findings.

1.7 Summary

The importance of accurately and rapidly characterizing oil palm fruitlets cannot be overemphasized as it is crucial for good selection processes, quality control as well as improved percentage production yield. The general overview of oil palm as a productive plant and its other uses apart from mainstream oil production have been presented in this chapter. Applications of softcomputing techniques have also been briefly explored. Furthermore, the problem statement and aim and objectives of this work have been spelt out including the research scope and limitation.

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