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DEVELOPMENT OF INDUCTIVE SENSOR FOR DETERMINING RIPENESS OF OIL PALM FRUIT

NOOR HASMIZA HARUN

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DEVELOPMENT OF INDUCTIVE SENSOR FOR DETERMINING RIPENESS OF OIL PALM FRUIT

By

NOOR HASMIZA HARUN

Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia in Fulfillment of the Requirements for the Degree of Doctor of Philosophy

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DEDICATION

To my beloved parents,

Haji Harun Ismail and Zaleiha Ahmad

My dearest husband

Rozaimi Abdul Jalil

& lovely kids,

Sufiya Dina Imani

Ukkashah Zuhayr

Lastly, my sisters and brothers,

Dr. Nor Hazlyna Harun
Zaharin Harun
Jannatunnaim Harun
Dr. Nurul Farihin Harun
Saifullah Ali Harun
Mohd Ridzuan Harun

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Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfillment of the requirements for the degree of Doctor of Philosophy

DEVELOPMENT OF INDUCTIVE SENSOR FOR DETERMINING RIPENESS OF OIL PALM FRUIT

By

NOOR HASMIZA HARUN

April 2015

Chairman : Norhisam Misron, PhD
Faculty : Engineering

Generally, the quality of the oil palm fruit is categorized based on the texture, shape and color of the fruit. In most of the oil palm miller in the world including Malaysia, the human expert grading approach is used to inspect the maturity of the oil palm Fresh Fruit Bunch and classify them for harvesting. Human inspection is a time-consuming method, inaccurate and often leads to mistakes where there is a high potential to grade the fruit wrongly. Therefore, an automated fruit grading system that is rapid, accurate and reliable is highly required.

In the prevailing research works, none of the grading method using inductive concept is proposed and as such, an inductive based oil palm fruit sensor is proposed in this thesis, based on the resonant frequency of the air coil. The proposed structure of the inductive oil palm fruit sensor was fabricated using a non conducting material consists of an air coil as a detection part and a holder. The air coil was coiled with a copper wire of numerous diameter. The development of the inductive oil palm fruit sensor started with a ring - type shape air coil followed by a flat - type shape air coil and a dual flat-type shape air coil. The experimental testing was conducted on two types of samples namely unripe and ripe fruitlets. These samples were freshly plucked on the day of the testing. To justify the practicality of the inductive based oil palm fruit sensor, a field testing was conducted at the end of the research works.

General evaluations on the resonant frequency started with the analysis of the inductance characteristics of the air coil. Then, the frequency characteristics were observed for all air coils, specifically the effects of the air coil's structure. The evaluation started with the value of the resonant frequency of the air coil was normalized. As for the inductance characteristics of the ring-type shape air coil, 24mm air coil's diameter shows the biggest difference between ripe to unripe samples. Results shows that 0.02643MHz significant difference between unripe

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sample to air and 0.01084MHz for ripe sample to air. As for the single flat-type air coil, the 5mm air coil's length with the 0.12mm coil diameter provides the highest percentage difference between sample and it is amongst the highest deviation value between samples. For the dual flat type air coil, the 200-140 turns configurations has improved by 371% in terms of the differences between the sample mean of both samples and 236% in terms of ratio between δ_{unripe} and δ_{ripe}, respectively. Finally, the field testing on three bunches of oil palm of different level of maturity displayed a growth graph of resonant frequency as the weeks passed. In sum, the inductive method of oil palm ripeness sensor offers few advantages such as passive sensor, reduced time consumption and accurate grading system. Besides, the inductive method emphasizing the resonant frequency has been proved reliable in determining the ripeness of the oil palm fruit bunches. With the advantages provided by this oil palm ripeness sensor, it is believed that inductive method would be a good alternative method to grade oil palm fruit.

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Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia
sebagai memenuhi keperluan untuk ijazah Doktor Falsafah

PEMBANGUNAN PENGESAN INDUKTIF UNTUK MEMERIKSA KERANUMAN BUAH KELAPA SAWIT

Oleh

NOOR HASMIZA HARUN

April 2015

Pengerusi : Norhisam Misron, PhD

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Umumnya, kualiti buah kelapa sawit dikategorikan berdasarkan tekstur, bentuk dan warna buah. Kebanyakan pengilang kelapa sawit di dunia termasuk Malaysia, pakar gred memeriksa kematangan buah kelapa sawit untuk tujuan pengklasifikasian semasa proses penuaian. Pemeriksaan oleh pakar gred ini memakan masa yang agak lama, tidak tepat dan berpotensi tinggi untuk berlaku kesilapan penggredan tandan yang salah. Oleh itu, sistem penggredan tandan kelapa sawit secara automatik yang cepat, tepat dan boleh dipercayai adalah diperlukan.

Dalam kerja-kerja penyelidikan semasa, tiada kaedah penggredan yang berasaskan konsep induktif digunakan. Pengesan buah kelapa sawit berasaskan induktif yang dicadangkan di dalam tesis ini adalah berdasarkan kepada resonan frekuensi gegelung udara. Struktur pengesan buah kelapa sawit berasaskan induktif yang direka menggunakan bahan bukan konduktif yang terdiri daripada gegelung udara sebagai alat pengesan dan pemegang. Gegelung udara dililit dengan wayar tembaga daripada pelbagai diameter. Pembangunan sensor buah kelapa sawit berasaskan induktif dimulakan dengan pembangunan gegelung udara berbentuk cincin diikuti oleh gegelung udara berbentuk rata dan dwi gegelung udara berbentuk rata. Eksperimen telah dijalankan kepada dua jenis sampel buah iaitu buah matang dan buah muda. Kesemua sampel ini telah dipetik pada hari ujian dijalankan. Untuk mengesahkan secara praktikal pengesan buah kelapa sawit berasaskan induktif ini, ujian di ladang kelapa sawit telah dijalankan di akhir kerja-kerja penyelidikan .

Penilaian umum pada frekuensi resonan bermula dengan analisis pada ciri-ciri kearuhan gegelung udara. Kemudian , ciri-ciri resonan frekuensi diperhatikan untuk semua gegelung udara , khususnya kesan struktur gegelung udara. Di awal proses analisis, nilai frekuensi resonan gegelung udara telah dinormalkan.

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Bagi ciri-ciri kearuhan untuk gegelung udara berbentuk cincin , gegelung udara bersaiz 24mm memberikan jurang perbezaan yang besar antara sample buah masak dan buah muda. Berdasarkan keputusan, beza berjumlah 0.02643MHz diantara sampel buah mentah terhadap udara dan 0.01084MHz di antara sampel buah matang terhadap udara hasil analisa ke atas diameter gegelung udara. Bagi dwi gegelung udara berbentuk rata, gegelung udara dengan panjang 5mm dan diameter gegelung iaitu 0.12mm telah mempamerkan perbezaan peratusan yang paling tinggi antara sampel serta nilai sisihan tertinggi. Ciri-ciri frekuensi resonan untuk dwi gegelung udara dengan konfigurasi 200-140 telah meningkat sebanyak 371 % untuk perbezaan purata antara kedua-dua sampel dan 236 % untuk nisbah antara δ_{unripe} dan δ_{ripe}. Akhir sekali, ujian yang dilakukan di ladang kelapa sawit ke atas tiga tandan kelapa sawit dengan tahap kematangan yang berbeza memaparkan graf pertumbuhan frekuensi resonan dengan menunjukkan pertambahan kiraan minggu. Pengesan berasaskan induktif untuk penggredan tahap keranuman kelapa sawit ini menawarkan beberapa kelebihan seperti sensor yang bersifat pasif, mengurangkan masa untuk proses penggredan serta dapat menghasilkan keputusan yang tepat. Selain itu, kaedah induktif yang menekankan frekuensi resonan telah dibuktikan sesuai digunakan untuk menentukan keranuman buah kelapa sawit. Dengan kelebihan yang ditawarkan, kaedah induktif yang dicadangkan dalam kajian ini menawarkan kaedah alternatif untuk proses penggredan buah kelapa sawit di masa hadapan.

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I certify that a Thesis Examination Committee has met on 24 April 2015 to conduct the final examination of Noor Hasmiza Harun on his Doctor of Philosophy thesis entitled "**Development of inductive based oil palm fruit sensor for determining the ripeness of oil palm fruit**" in accordance with Universities and University Colleges Act 1971 and the Constitution of the Universiti Putra Malaysia [P.U.(A) 106] 15 March 1998. The Committee recommends that the candidate be awarded the Doctor of Philosophy. Members of the Thesis Examination Committee were as follows:

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This thesis submitted to the Senate of Universiti Putra Malaysia and has been accepted as fulfilment of the requirement for the degree of Doctor of Philosophy. The members of the Supervisory Committee were as follows:

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LIST OF ABBREVIATIONS

FFB	Fresh Fruit Bunch
RGB	Red Green Blue
MRI	Magnetic Resonance Imaging
NMR	Nuclear Magnetic Resonance
NIR	Non-destructive near Infra Red
PLSR	Partial Least Squares Regression
MPOB	Malaysian Palm Oil Board
WAA	Week after anthesis
DLE	Delayed Light Emission
HSI	Hue, Saturation and Intensity
LED	Light Emitted Diode
ANN	Artificial Neural Network
PCA	Principal Component Analysis
DN	Digital Numbers
GUI	Graphical User Interface
f_r	Resonant frequency
$\lvert X \rvert$	Magnitude of impedance
ω	Angular frequency
f	Frequency
L	Inductance
C	Capacitance
N	Number of turns
Φ	Flux
$\mu_{0,}$	Permeability of free space
μ_r	Permeability of material
A	Cross sectional area
l	Length of the wire
D_{out}	Outer diameter of air coil
D_{in}	Inner diameter of air coil

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$D_{CC\text{out}}$	Outer diameter of coil casing
$D_{CC\text{in}}$	Inner diameter of coil casing
h_{out}	Outer height
h_{in}	Inner height
l_{out}	Outer length
l_{in}	Inner length
w_{out}	Outer width
w_{in}	Inner width
l_{c}	Air coil's length
d_{c}	Coil's diameter
f_{ra}	Resonant frequency of air
f_{rr}	Resonant frequency of ripe sample
f_{ru}	Resonant frequency of unripe sample
$\mathrm{N}f_{\text{ra}}$	Normalized resonant frequency of air
$\mathrm{N}f_{\text{rr}}$	Normalized resonant frequency of ripe sample
$\mathrm{N}f_{\text{ru}}$	Normalized resonant frequency of unripe sample
f_{r1}	Resonant frequency of the first peak
f_{r2}	Resonant frequency of the second peak
f_{r1a}	Resonant frequency of air for the first peak
f_{r2a}	Resonant frequency of air for the second peak
f_{r1r}	Resonant frequency of ripe sample of the first peak
f_{r2r}	Resonant frequency of ripe sample for the second peak
f_{r1u}	Resonant frequency of unripe sample of the first peak
f_{r2u}	Resonant frequency of unripe sample for the second peak
$\overline{f_{r1a}}$	The sample mean for f_{r1a}
Nf_{r1a}	Normalized resonant frequency of air for the first peak
Nf_{r1r}	Normalized resonant frequency of ripe sample for the first peak
Nf_{r1u}	Normalized resonant frequency of unripe sample for the first peak
$\overline{Nf_{r1a}}$	The sample mean for $\mathrm{N}f_{\text{r1a}}$
$\overline{Nf_{r1r}}$	The sample mean for $\mathrm{N}f_{\text{r1r}}$

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$\overline{Nf_{r1u}}$	The sample mean for Nf_{r1u}
$\overline{f_{r2a}}$	The sample mean for f_{r21a}
$\overline{Nf_{r2a}}$	The sample mean for Nf_{r2a}
$\overline{Nf_{r2r}}$	The sample mean for Nf_{r2r}
$\overline{Nf_{r2u}}$	The sample mean for Nf_{r2u}
Nf_{r2a}	Normalized resonant frequency of air for the second peak
Nf_{r2r}	Normalized resonant frequency of ripe sample for the second peak
Nf_{r2u}	Normalized resonant frequency of unripe sample for the second peak
$\overline{Nf_{ra}}$	The sample mean of air
$\overline{Nf_{rr}}$	The sample mean of ripe sample
$\overline{Nf_{ru}}$	The sample mean of unripe sample
δ_{ripe}	the difference between the sample mean of air to ripe sample
δ_{unripe}	The difference between the sample mean of air to unripe sample
$\delta_{percentage}$	Percentage difference
$\overline{\delta_{Nf_{ra}}}$	the average value for the difference between the mean sample of air
$\overline{\delta_{Nf_{rr}}}$	the average value for the difference between the mean sample of ripe sample
$\overline{\delta_{Nfru}}$	the average value for the difference between the mean sample of unripe sample

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CHAPTER ONE

INTRODUCTION

1.1 Background

In recent years, Malaysia is listed as one of the developing countries in Asia that has productively transformed from an exporter of raw materials into a diversified economy. Services sector has become the main contributor to the economy, accounting for around 54% of GDP. Manufacturing sector has been expanding rapidly and now accounts for 25% of GDP and more than 60% of total exports in Malaysia. Whilst mining and quarrying contributes 9% of GDP and agriculture 9% respectively[1].

Figure 1.1 : Malaysia GDP Annual Growth [1]

In view of agriculture, natural rubber and palm oil, which together with sawn logs and sawn timber, cocoa, pepper, pineapple and tobacco are the main exports which dominate the sector's growth. Palm oil industry has become the major contributor of foreign exchange [2]. The oil palm plantation constitutes the largest oil crops in Malaysia with a reported average annual production of 4.0 metric tonne of palm oil per hectare of land. To ensure that maximum amount of palm oil extracted from the mesocarp, it is important that the oil palm FFBs are harvested at the correct stage of ripeness [3-4]. In current practice, the quality of the oil palm fruit is categorized based on the texture, shape and color of the fruit [3]. The human expert grading approach is employed to inspect the maturity of the oil palm FFB and classify them for harvesting. Referring to the grading manual by the Malaysian Palm Oil Board, the color of the surface of the fruit and the number of loose fruit drops from bunches are the two main factors used by the human expert [3- 4]. However, human grader has a high potential to grade the fruit wrongly and a time-consuming method. These factors often lead to considerable losses [5-6] and as such, an automated fruit grading system which is rapid, accurate and reliable is highly required. Apart from that, it should not destruct the palm oil FFB during the qualitative analysis [7-8].

In the past few years, various automated fruit grading systems were proposed and tested by the Malaysian researchers. Among the popular methods used are the color vision system, the moisture content assessment, the imaging method and a capacitive based assessment [9-12]. However, the main drawback of these methods is all of them is suitable for indoor application. Almost all of these methods require supporting equipment in the assessment, thus limits the outdoor testing.

This thesis presents a novel grading method based on the inductive concept that is not in the prevailing research list yet. The inductive concept has been chosen in this study based on its passive characteristics and simple to construct. The inductive based oil palm fruit sensor emphasizes the resonant frequency of its air coil and translate them to characterize the sensor. The primary design of the air coil (the ring - type shape air coil) presents its frequency characteristics specifically on the effects of air coil's diameter in the preliminary research work [13-14]. The research continues with a new design of air coil structure. The single flat type air coil with various air coil's length and coil's diameter range is studied. Then further investigation on the single flat type air coil is presented with the proposed dual flat type air coil. Two flat type air coils with different number of turns, *N* are used in the testing. A comparative analysis between the single flat type air coil and the dual flat type air coil is made at the end of the testing to observe its improvement especially in terms of sensitivity. Then, a field testing is conducted at the end of the research works to verify the efficiency of the inductive based oil palm fruit sensor for the outdoor application.

1.2 Problem Statement

Human grader has become the most popular method among most of the oil palm millers in Malaysia. The manual grading method proposed by the Malaysian Palm Oil Board (MPOB) has become the main reference for the human grader during the maturity inspection prior to harvesting process. The human grader inspects the matured oil palm fresh fruit bunch (FFB) based on the surface color of the fruit and the number of fruit loose from the bunch. However, the main concern in this technique is, different human graders will provide different judgment, time consuming and it has a very high possibility of providing inaccurate result. Therefore, an automated grading system has become an important issue to resolve among Malaysian researchers.

Various numbers of automated oil palm fruit grading systems were proposed and tested recently. The most popular is the use of the color vision system that requires an advanced digital camera used to capture the image of oil palm FFB and a computer set for data analysis [8-9,15]. In common, a programmable recognition system is developed using artificial intelligence such as Red, Green and Blue (RGB), neural network, Hue and etc [16-17]. However, the color vision system is only suitable for indoor application due to its complicated equipment and the required continuous light intensity monitoring during the image acquisition process. As the moisture content of the mesocarp affects the surface color and the weight of the oil palm fruit, analyzing it has become interest to some researchers. In this method, microwave moisture sensors are used to investigate the moisture content of oil palm [18-19]. However, the procedure to conduct the measurement is quite complicated

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and time-consuming. Apart from that, this method is only suitable for indoor application and the equipment is quite expensive. Other than this, Magnetic Resonance Imaging (MRI) and bulk Nuclear Magnetic Resonance (NMR) are also examples of costing methods used by researchers to monitor the development and ripeness of oil palm FFBs [11]. The changes between oil and moisture content in the oil palm FFBs are observed based on the differences in their spin-spin relaxation times and a significant result is obtained. Other than the usage of complicated and expensive equipment, skilled personnel are needed to operate it, limiting the testing to be done indoors. Non-destructive near Infra Red (NIR) spectroscopy is another example of imaging method used to grade the oil palm FFB. In this method, two NIR spectrometers are used to scan the oil palm fruits with different modes and the chemical contents of palm oil are analyzed using Partial Least Squares Regression (PLSR) models [20]. Similarly with other imaging techniques, on top of the complicated sample preparation and expensive equipment used, the method is only suitable for indoor application. Capacitive concept is also one of the method used to measure dielectric properties of the oil palm fruit[12]. Similar to the other methods, capacitive method requires supporting equipment and it is not suitable for outdoor testing.

Therefore, this research focuses on the development of the novel inductive based oil palm fruit sensor so that it can be reliably used to grade the oil palm FFB and practically used for outdoor application. The inductive concept is chosen due to its simple principle and direct translation of output from the sensor to grade the fruit. The stabilized resonant frequency of the air coil has become the detection principles of the sensor. The whole structure of the sensor is designed and fabricated in a portable structure and practical to be used outdoors. Added to the above, the inexpensive material selected for the structure is not easily affected by the environment. Therefore, this oil palm fruit sensor based on inductive concept is reliable to replace the conventional grading method.

1.3 Objectives

Based on the discussed problem statement above, several objectives are identified for this research. These objectives are listed as below:

1. To investigate the reliability of the inductive concept to inspect the maturity of the oil palm fruit.
2. To propose and design the structure of the inductive based oil palm fruit sensor.
3. To develop a novel inductive based oil palm fruit sensor for indoor and outdoor application
4. To analyze and evaluate the effects of sensor's structure to improve its performance.
5. To conduct a field testing to verify its reliability for outdoor application.

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1.4 Thesis Contributions

The main contribution of the thesis is the development of the novel inductive based oil palm fruit sensor for determining the maturity of the oil palm FFB. The detection principles based on the resonant frequency of the air coil is evaluated as its stabilized characteristics over the amplitude. Accordingly, three types of air coil structure are designed and fabricated. Therefore, the sensitivity of the inductive oil palm fruit sensor is improved with the analysis on the dual resonant frequencies from the proposed design of air coil's structure. From the viewpoint of knowledge contribution, the development of inductive based oil palm fruit sensor proves the capability of the inductive element as a detection element for determining the maturity of the oil palm FFB. Besides, the analysis on the air coil's structure provides guidelines for optimum performance of the inductive oil palm fruit sensor. Furthermore, the series of experiments conducted indoor and outdoor enhance the possibility of the inductive oil palm fruit sensor to be used as alternative method in determining the maturity of the oil palm FFB in the future.

1.5 Scope of Work

In this research, the development of the inductive based oil palm fruit sensor is initiated with the proposal of the sensor's structure. Then, the basic principle of the inductive oil palm fruit sensor is studied. Next, the proposed design is fabricated using a non conducting material. Three different types of air coil are fabricated and tested in this research. The air coil's structure is then analyzed on different parameters to observe the effects of the structure to the sensitivity of the sensor.

Another scope of this research is to evaluate the performance of each fabricated air coil to measure its sensitivity. This include a field testing conducted into three bunches of oil palm fruit with different level of maturity.

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1.6 Thesis Outline

Chapter One gives an overview of the present research and as such, it includes an introduction about the research, problem statement, scope of work and objectives of the research. The introduction explains the current methods implemented among all the oil palm millers in Malaysia to determine the maturity of the oil palm FFB and the latest invention in the automated grading system conducted by the researchers. Moreover, the problem statement addresses the motivations needed to carry out this research, the listed objectives show the aim behind the research and finally, the scope of work provides the methodology outline to be employed in this research.

Chapter Two briefly explains the common grading method used for fruit and vegetables in horticultural field. This chapter also discusses the characteristics of the palm oil tree including its fruits, its maturity level and the chemistry of the fruitlet. Then, the conventional grading method implemented by the human grader is further explained along with the sample preparation for two categories of fruit sample. This chapter also discusses several related researches dedicated to automated grading method that were presented in various studies. Lastly, this chapter explains the basic principle used in the sensor's detection specifically the resonant frequency, the inductance and the air cored coil.

Chapter Three describes the research methodology with an explanation of the basic concept of detection. Then, the electrical diagram representing each air coil's structure is discussed and the designing stages of the novel inductive based oil palm fruit sensor including the fruit holder and the air coil are described. This is followed by the overview of the fabrication of three types of air coil structure. For this purpose, a measurement method is developed and standardized throughout the study. A detailed measurement method used in this study is elaborated in this chapter followed by the explanation of the evaluation method on each air coil. The evaluation method for each air coil is important as a guideline in designing the air coil's structure in the future. Finally, a field testing, conducted at the end of the study, is explained and discussed.

Chapter Four discusses the analysis of the air coil's structure of each air coil used in this study. The coil inductance characteristics and the resonant characteristics of each air coil are presented at the beginning of the each air coil's section. Then, each air coil's parameter is further analyzed and discussed in each respective section. Furthermore, evaluation result of all air coils used in this study is also presented in the chapter. For final evaluation, a field testing is conducted to justify the practicality of the inductive based oil palm fruit sensor to be used for outdoor application.

Chapter Five presents the conclusion of the overall research in term of the design process and the analysis result. This chapter also includes a few recommendations that can be implemented in this research field in the future.

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