UNIVERSITI PUTRA MALAYSIA

DEVELOPMENT OF FRUIT BATTERY SENSOR WITH CHARGING METHOD FOR OIL PALM FRUIT RIPENESS DETECTION

NISA SYAKIRAH BINTI KAMAL AZHAR

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By

NISA SYAKIRAH BINTI KAMAL AZHAR

Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfilment of the Requirements for the Degree of Master of Science

February 2021

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirement for the degree of Master of Science

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Chair : Norhisam bin Misron, PhD
Faculty : Engineering

The oil palm fresh fruit bunches (FFB) has different maturity grading according to MPOB guidelines. Throughout the transferring process of FFB to the mills, the reception process of the FFB might contain various type of gradings which could affect the quality of the oil production. The FFB harvest from the oil plantation might be in low quality grading, immature or rotten when inspected during mills inspection. Since the FFB received at the mills might not be matured or ripen enough due to those several factors, human inspection using eyes could not measure the ripeness content that can give inaccurate grading of the FFB to be processed. Thus, a sensor or measuring instrument that highly sensitive and reliable is needed to measure and analyse the various grading of the oil palm fruit. Based on previous research works, none of the method using the charging method to be applied to the fruit battery experiment where in this study, a fruit battery-based sensor with a charging mechanism is proposed. An oil palm fruit battery sensor is designed and fabricated with aluminium and copper electrodes to test on the oil palm fruits from the FFB. The fabrication of the sensor consisted of four different types namely single, dual, three and fourth-set terminal type. Each structure of the sensor consisted of different pairs of electrodes number and different dimension size. The experimental measurement was conducted on various samples collected on the day of the testing such as ripe, under-ripe and unripe. Parameters of load resistance R_L, charging voltage, V_c, and charging time, t_c are tested and compared to identify its effectiveness and the best condition in sensor sensitivity performance. The evaluation from the moisture content determination is taken to compare the values and correlation with the average load voltage, V_{avg} obtained. A basic mathematical expression is used to analyse the graphical result by using integration and fitting line expression to conclude the ideal parameter set for the electrochemical cell sensor. A sensitivity performance is calculated to justify the development of the different types of sensor. Ideal parameters of R_L=100Ω,

V_c=250V and t_c=10s are chosen to test on the other sensors where the development of electrodes numbers increases the sensitivity performances. A comparison of the sensor performance with a different set of the terminal is compared to identify the ideal sensor for ripeness detection. Thus, from the test results, it was found that the fourth-set type has the highest sensitivity which is 0.586 and the sensor performance increases around 154.78% from single to the fourth-set terminal sensor type. In conclusion, the charging method improving the sensitivity of the fruit battery sensor and it is verified that the sensor can determine the ripeness of the oil palm sensor. From the data consisted different parameters value, it is assumed that it can be a reference and alternative technique to grade the oil palm FFB ripeness.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Master Sains

PEMBANGUNAN PENDERIA BATERI BUAH DENGAN KAEDAH PENGECASAN UNTUK PENGESANAN KEMATANGAN BUAH KELAPA SAWIT

Oleh

NISA SYAKIRAH BINTI KAMAL AZHAR

Februari 2021

Pengerusi : Norhisam bin Misron, PhD
Fakulti : Kejuruteraan

Tandan buah segar kelapa sawit (TBS) mempunyai penilaian kematangan yang berbeza mengikut garis panduan MPOB. Sepanjang proses pemindahan TBS ke kilang, proses penerimaan TBS mungkin berisi berbagai jenis penggredan yang dapat mempengaruhi kualiti produksi minyak. Penuaian TBS dari ladang minyak mungkin dalam tahap penilaian rendah, tidak matang atau busuk ketika diperiksa selama pemeriksaan oleh kilang. Oleh kerana TBS yang diterima di kilang mungkin tidak cukup matang atau tidak cukup masak kerana beberapa faktor tersebut, pemeriksaan manusia menggunakan mata tidak dapat mengukur kandungan kematangan yang dapat memberikan penilaian TBS yang tidak tepat untuk diproses. Oleh itu, penderia atau alat ukur yang sangat sensitif dan boleh dipercayai diperlukan untuk mengukur dan menganalisis pelbagai penilaian buah kelapa sawit. Berdasarkan karya penelitian sebelumnya, tidak ada satu pun kaedah yang menggunakan kaedah pengecasan untuk diterapkan pada eksperimen bateri buah di mana dalam kajian ini, penderia berasaskan bateri buah dengan mekanisme pengecasan. Penderia bateri buah kelapa sawit direka dan dibuat dengan elektrod aluminium dan tembaga untuk menguji buah kelapa sawit dari TBS. Fabrikasi penderia terdiri daripada empat jenis yang berbeza iaitu jenis terminal tunggal, berganda, tiga dan empat. Setiap struktur penderia terdiri daripada pasangan bilangan elektrod yang berlainan dan ukuran dimensi yang berbeza. Pengukuran eksperimen dilakukan pada pelbagai sampel yang dikumpulkan pada hari ujian seperti masak, belum matang dan belum masak. Parameter rintangan beban, R_L, voltan pengecasan, V_c dan masa pengecasan, t_c, diuji dan dibandingkan untuk mengenal pasti keberkesanannya dan keadaan terbaik dalam prestasi kepekaan penderia. Penilaian dari penentuan kadar kelembapan diambil untuk membandingkan nilai dan korelasi dengan voltan beban purata, V_{avg}, yang diperoleh. Ungkapan matematik asas digunakan untuk menganalisis hasil grafik dengan menggunakan integrasi dan ekspresi garis sesuai untuk menyimpulkan set parameter ideal untuk penderia sel elektrokimia. Prestasi kepekaan dikira untuk membenarkan perkembangan pelbagai jenis penderia. Parameter ideal R_L=100Ω, V_c=250V dan t_c=10s dipilih untuk diuji pada penderia lain di

mana pengembangan nombor elektrod meningkatkan prestasi kepekaan. Perbandingan prestasi penderia dengan set terminal yang berbeza dibandingkan untuk mengenal pasti penderia yang diidamkan untuk pengesanan kematangan. Oleh itu, dari hasil ujian, didapati bahawa jenis set keempat mempunyai kepekaan tertinggi iaitu 0.586 dan prestasi penderia meningkat sekitar 154.78% dari satu ke jenis penderia terminal set keempat. Kesimpulannya, kaedah pengecasan meningkatkan kepekaan penderia bateri buah dan disahkan bahwa dapat menentukan kematangan penderia kelapa sawit. Dari data yang terdiri dari nilai parameter yang berlainan, dirumuskan dapat menjadi rujukan dan teknik alternatif untuk menilai kematangan TBS kelapa sawit.

ACKNOWLEDGEMENTS

All praise to Allah. I cannot achieve and succeed without His guidance and permission throughout this research been done. Thank you to Allah for making who I am today in succeeding my future one step ahead of my dream in taking a Master programme.

First of all, a big thanks to my supervisor, Prof. Dr. Norhisam Misron, for his guidance and help in conducting and finishing this research project. Also, I would like to express my gratitude to my co-supervisors, Prof. Dr. Ishak Aris and Prof. Dr. Mohd. Nizar Hamidon for their suggestions and additional knowledge in completing this research.

Thank you to my family for the support of whether mentally or financially throughout this project has been done and to my friends here for cheering me up, which was a memory that I will cherish forever.

Lastly, thank you to Universiti Putra Malaysia for giving me this opportunity to continue studying to gain more research and technical knowledge for future works, especially in providing financial support for my research progression.

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

Norhisam bin Misron, PhD
Professor
Faculty of Engineering
Universiti Putra Malaysia
(Chairman)

Ishak bin Aris, PhD
Professor
Faculty of Engineering
Universiti Putra Malaysia
(Member)

Mohd Nizar bin Hamidon, PhD
Professor
Faculty of Engineering
Universiti Putra Malaysia
(Member)

____
ZALILAH MOHD SHARIFF, PhD
Professor and Dean
School of Graduate Studies
Universiti Putra Malaysia

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Name of Member of Supervisory Committee: ______________________________

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LIST OF ABBREVIATIONS

UPM	Universiti Putra Malaysia
FFB	Fresh Fruit Bunches
GDP	Gross Domestic Product
FGV	Felda Global Venture
MYR	Malaysian Ringgit
NIR	Near Infrared
CPO	Crude Palm Oil
PKO	Palm Kernel Oil
MPOB	Malaysian Palm Oil Board
CCRD	Central Composite Rotatable Design
FFA	Free Fatty Acids
RGB	Red, Green and Blue
CMOS	Complementary Metal Oxide Semiconductor
MRI	Magnetic Resonance Imaging
NMR	Nuclear Magnetic Resonance
WAA	Weeks After Anthesis
OER	Oil Extraction Rate
AR	Augmented Reality
DAP	Days of Pollination
COP	Code of Practice
HIS	Hue, Saturation and Intensity
ENVI	Environment for Visualising Images
WEKA	Waikato Environment for Knowledge Analysis
DN	Digital Number

GIS	Geographic Information System
LiDAR	Light Detection and Ranging
3D	3-Dimensional
2D	2 -Dimensional
IR	Infrared Wavelength
ANN	Artificial Neural Network
KNN	K-Nearest Neighbours
SVM	Support Vector Machine
BGLAM	Basic Grey Level Aura Matrix
ANOVA	Analysis of Variance
BRR_FRF	Blue-to-Red Fluorescence Ratio
UV	Ultraviolet
LED	Light Emitting Diode
BGF	Blue-Green Factor
FRF	Far-Red Fluorescence
C&RT	Classification and Regression Tree
ND	Neutral Density
GANN	Genetic Algorithm Neural Network
Al	Aluminium
Zn	Zinc
Cu	Copper
GA	Gibberellic acid
MLR	Multiple Linear Regression
PCR	Principal Component Regression
PLS	Partial Least Square
PSII	Photosystem II

DLE	Delayed Light Emission
Micro-CT	Micro-computer tomography
MATLAB	Matrix Laboratory
ROI	Region of Image
BMP	Bitmap
PCA	Principal Component Analysis
MAE	Mean Absolute Error
RMSE	Root Mean Squares Mean
CCD	Charge-Couple Device
CCRD	Central Composite Rotatable Design (CCRD)

LIST OF SYMBOLS

w_b	Weight before experiment
w_a	Weight after experiment
V_L	Load voltage
R_L	Load resistance
V_c	Charging voltage
t_c	Charging time
t_A	Area of a time
V_{avg}	Average load voltage
V_{max}	Maximum load voltage
V_h	Power supply
w	Moisture content
ΔW	Moisture content difference
$\Delta V_{m, avg}$	Average effective load voltage
$\Delta V_{s, m, avg}$	Difference of average effective load voltage
ΔV_{avg}	Difference of average voltage
h	Height
d	Diameter
l	Length
h_e	Height of the electrode
d_e	Diameter of the electrode
l_{e-c}	Length of the electrode to the centre
R^2	Coefficient of determination
P	Probability of an error
Zn^{2+}	Zinc ion

Al^{3+}	Aluminium ion
H^+	Hydrogen ion
H_2	Hydrogen gas
e^-	Electron

CHAPTER 1

INTRODUCTION

This chapter explains the general information on the research project. The related research problems are explained and elaborated with several objectives to improve and implement the research work regarding the problems. The work attribution for each chapter is explained in this part with the outline of this research study.

1.1 Background

The oil palm industry in Malaysia is known to be one of the aspects of contributing growth to our country's economy. It was nearly 100 years of the oil palm industry started since it was first introduced in 1917. In the last five years, the oil palm industry contributed around five to seven percent to Malaysia's Gross Domestic Product (GDP) with RM64.24 billion annually in its export revenue. Furthermore, the expansion of the oil palm market globally exported to more than 190 markets show the high demand for oil palm products. Therefore, Malaysia has considered one of the biggest exporters and producers of oil palm products that it is essential for worldwide needs, which increased the country economically [1]. The oil palm *Elaeis guineensis* type is well known to be used due to its thin endocarp and thick mesocarp with an average size of the kernel, which also relates to palm oil's growing demand whether locally or globally [2]. Sustainable palm oil production encouraged the industry, governments and researchers to increase the yield of oil palm productivity [3]. Generally, there are two types of oil derived from the oil palm fruit: crude palm oil (CPO) and palm kernel oil (PKO). High quality CPO is extracted from the fresh mesocarp of oil palm fruit in the milling process while the palm kernel is delivered to other mills for PKO extraction. The oil production undergoes several milling processes such as crushing, sterilisation, threshing, etc., after receiving the fresh fruit bunches (FFB). The increment in palm oil markets has shown that the oil extraction rate (OER) is one of every mill's main focuses to achieve in their target [4]. It shows that the grading of the oil palm fruit procedure is one of the central parts that play an important role in a good quality grade of FFBs. About 80 million Malaysian Ringgit (MYR) lost as what happened to Felda Global Venture (FGV) before 2017 due to unripe bunches reception from the settlers [5]. This defines that the mill's role needs to consider every aspect in producing great quality OER. According to the oil palm grading manual published by the Malaysian Palm Oil Board (MPOB), the standard procedure or method for grading the oil palm fruits is generally performed by visual inspection of human graders. The inspection procedure is performed based on the visual colour characteristic on the surface of the FFB and the number of loose fruits detached from the bunch [6].

During the previous few years, various methods of study on oil palm fruit ripeness have been introduced and developed throughout many years. One of the popular methods in oil palm grading is a colour vision system with RGB and an image acquisition process [50-53]. Other method involving infrared [54-56], ANN [57], laser-based [58-61], temperature [62], fluorescence [64-65], MRI with NMR [63] and inductive concept

[66-70] are introduced and tested. However, the main issue of all these methods is the testing suitable for indoor application and complicated equipment where it limits the outdoor testing.

This thesis presents a fruit battery concept with a charging method that is not practised in the current research study yet. The fruit battery with charging concept idea has a passive characteristic and simple to design where it has become one of the reasons the idea of the study is chosen. The charging concept approach is used in this method to emphasize the differences between various oil palm grade and conclude the ideal sensor that has the highest sensitivity performances for detection. The primary fruit battery design shows its effect in different load resistance testing with specific dimension structure of electrodes in the previous research work [71-72]. The research then continues with computer vision to compare the features tested. Then, a fruit battery with different materials to replace the previous research study using aluminium and copper is introduced in this thesis for ripeness detection. The current fruit battery sensor is designed and fabricated so that it can be tested and implemented with a simple method in maturity detection. Hence, the charging concept is suggested to improve the sensitivity of the sensor and undergo comparative analysis between different types of sensor.

1.2 Problem Statement

Oil palm grading process is one of important aspect needs to be considered for better palm oil extraction rate (OER). Varies factors started from the harvesting of the FFB to the mills that might affect the mills' OER performance. The human grader to grade the oil palm fruits has always been the traditional way to determine the ripeness of the FFB [6]. Nonetheless, the human grader's visual inspection may lead to an error when clarifying the ripeness of the bunch by looking only at the colour surface and the fruits loose from the bunch. The problem included when some of the FFBs that are left out or forgotten during transportation, make the bunches turning to over-ripe or not fresh anymore by the next harvesting. Some of the ripe bunches left out not harvested might turn to over-ripe by the next time harvesting round [7]. These problems will occur during the inspection procedure because the naked eyes of human workers could not determine the ripeness of the oil palm for a better oil extraction rate. The categorisation of oil palm ripeness FFB during the mill's inspection to obtain the quality and high oil content of FFBs will be the main challenge for great grading procedure. Hence, this problems lead to various research technology implemented to determine the ripeness of the oil palm FFB. Hence, a system using automated grading for ripeness detection has become an important matter to study and solve among researchers.

There are various numbers of oil palm ripeness detection technique were introduced and tested. The most popular method is the colour vision system that comprises an advanced camera to capture the oil palm FFB image and a set of a computer for analysis and interpretation [50-53, 57]. Similar to the colour vision method, a system using program recognition with artificial intelligence such as Red, Green and Blue (RGB), Hue, Saturation and Intensity (HSI), etc. Nevertheless, this method is using continuous light intensity observing during the image acquisition process and preferably to be conducted for indoor application because of its complex apparatus or equipment. Moreover, the development of a more advanced technique is further studied when the moisture content of the mesocarp flesh related to the oil content, surface colour and weight of the oil palm fruit. A near infrared (NIR) spectroscopy is one of the applications used to detect oil palm ripeness. Several NIR spectroscopy introduced has used a different approach where geographic information system (GIS) and genetic algorithm neural network (GANN) together with microstrip sensor to correlate the moisture content [54-56]. However, this method has a complicated procedure for image acquisition where it is also suitable for indoor application and the equipment involved is costly. Other than that, a non-destructive method using laser-based is used for oil palm grading where several approaches such as using LiDAR sensor, NIR laser, Raman spectroscopy, optical probe, etc are applied with specific wavelength to identify the level of the ripeness [56, 58-61]. Similar to the imaging techniques and NIR method where the equipment is expensive and suitable for indoor area. Furthermore, a method to detect the ripeness of oil palm FFB using sterilisation process [62] with different high temperature is proposed but the method suitable to be conducted in the indoor area and required expensive mechanical instrument. Magnetic Resonance Imaging (MRI) and Nuclear Magnetic Resonance (NMR) are some of the techniques that are costly used and studied by researchers to observe the oil palm ripeness [63]. Apart from the expensive issue, the procedure needed to be operated with skilled personnel and limited testing for the availability to be conducted indoors. Another non-destructive technique is suggested by using a fluorescence sensor to measure the anthocyanin and flavonoid in the oil palm content [64-65] where the light emitting diode (LED) and photodiodes are involved for signal emission. However, the method is similar to the RGB system where the experiment is suitable for indoor application to identify the chemical content of the oil palm fruits. An air coil technique is one of the methods used to measure the oil palm ripeness and it is developed from single until triple type sensor [66-70].

A new study area in a non-destructive method to detect the oil palm FFB ripeness is introduced by using a fruit battery sensor [71-72]. This method used zinc and copper as the sensor and with computer vision to analyse the colour condition images. However, the fruit battery sensor is not fabricated which might lead to instability of the data and a proper recording measuring instrument is needed to show the significant difference between various fruit types. Therefore, this research focuses on the development of a fruit battery sensor with a charging method so that it can be convincedly used to measure the oil palm ripeness in both indoor and outdoor application. The charging concept is chosen because of the direct output translation to detect the grading. The aluminium and copper electrode are proposed and fabricated in a portable structure so they can also be used in outdoor condition. Besides, the materials chosen are taken under consideration aspect that not easily affected by the environment. Hence, this aluminium and copper fruit battery sensor with the charging method is stable to replace the conventional grading method.

1.3 Objectives

The objectives of the research are as follows:

1. To develop a fruit battery-based sensor for oil palm fruit maturity assessment
2. To analyse and improve the maturity detection of oil palm fruits of fresh fruit bunches (FFB) by using a fruit battery-based sensor with a charging concept.
3. To study the relationship between generated load voltage and moisture content with sensitivity performance of the sensor
4. To compare and evaluate the preferred design performance of the various fruit battery sensor types with different parameters for the oil palm maturity detection.

1.4 Thesis Contributions

This thesis's contributions include the development of the fruit battery sensor with a charging concept to determine the ripeness of oil palm maturity grading for the reception of the FFB at the mills. The sensor comprises two materials of aluminium (Al) and copper (Cu), which then the sensor of fruit battery is designed and fabricated to different sets of terminals. Previous experimental [71] was done by using the fruit battery concept is implemented by using zinc (Zn) and copper (Cu) material as the electrodes for the sensor. The maturity of the oil palm fruits tested is analysed based on the average load resistance voltage with the fruit's moisture content to determine the sensor's sensitivity. In this thesis, the charging concept is the main parameter applied to the fruit battery experiment. The development of this research sensor aims to improve and determine the sensitivity of the detection method when identifying the maturity grading of the oil palm fruits. The data collected from the samples with their moisture content determination are analysed to distinguish and compare the sensor's performance.

1.5 Scope of Work and Limitation

The electrochemical cell sensor of aluminium and copper is developed based on the previous fruit battery sensor [79]. The designation of the sensor is executed by using SolidWorks software before the fabrication of different sensor's type. There are four types of sensor's fabrication terminal set: single, dual, triple and fourth. The parameters implemented in this experiment are conveyed into three kinds, which are the load resistance, R_L, charging voltage, V_c and charging time, t_c. The single set of sensor's terminals consist of aluminium (Al) and copper (Cu) electrodes. The other types are dual, triple and fourth-set sensor emphasized the set of Al and Cu terminal. The samples taken in this research are randomly picked with various kinds of grading such as ripe, under-ripe and unripe from different FFB. *Elaeis guineensis* of *Tenera* is the type of samples used to test for this experiment. The research is conducted mainly in laboratory condition at room temperature at all times. The experiment's time takes one hour for each drying process that takes much time to complete in one day. Hence, sensitivity evaluation is measured in this research study by analysing the performances from the ratio between difference voltage ΔV_{avg} and moisture content w from 50% to 80%.

1.6 Thesis Outline

Chapter One comprises the general overview of the research, which includes background, past and current problems regarding the research, objectives, thesis contributions, scope of work and limitation of the research. The thesis's background explained the oil palm in Malaysia and the current technology or method used to identify the ripeness or maturity grading of the oil palm fruit. The problem statement is elaborated regarding the current problems on oil palm harvesting and grading of the FFB. Hence, the scope of work explains the electrochemical cell sensor design implemented before and the limitation of the research.

Chapter Two presents the depth of knowledge of the research for further investigation. The oil palm grading in Malaysia by referring to the MPOB manual is explained to elaborate the ripeness of the FFB. The oil palm biological is also described in this part, such as its fruit content, trees, and structure. The research related to the oil palm ripeness technologies and equipment is elaborated and summarised. The guideline of the oil palm harvesting manual is included to show the type of FFB ripeness according to MPOB. Lastly, the electrodes metal and ion mechanism and the sensor's sensitivity are elaborated in this chapter.

Chapter Three includes the methodology of all the work and experiments done in this research. The concept and method of applying fruit battery as an electrochemical cell are explained with its design, schematic diagrams and structure. Then, the basic and proposed fruit battery concept is explained further on the chemical reaction related to the oil palm fruit content. Moreover, the charging method applied to the experiment is included with a list of various parameters tested: resistance value, charging voltage and charging time. The type of sensor used is included, which are single, dual, triple and fourth-set terminal with the structure and measurement. Furthermore, the collection of samples and data with moisture content determination experiment is further elaborated in this chapter. Lastly, basic mathematical expression of integration and polynomial fit are included.

Chapter Four explains the result of the data obtained from the oil palm sensor. The chapter begins with the comparison between basic fruit battery and during involving charging method in the experiment. The effect of the sensor's sensitivity in 100Ω and 510Ω is examined with different charging voltage and charging time for a single-set terminal sensor. The dual, triple and fourth-set terminal sensor then is tested with one specific parameter from the previous experiment to evaluate the sensor sensitivity when increasing numbers of electrodes are added. Finally, the coefficient of the variation model is summarised to compare with the previous and fruit battery sensor's performance.

Chapter Five reviews the conclusions of the overall finding research. The recommendations, ideas and suggestions are included for future research findings.

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BIODATA OF STUDENT

Name given is Nisa Syakirah binti Kamal Azhar. Born at Ipoh, Perak on 19th May 1995. Started primary education at Sekolah Kebangsaan Klian Pauh in Taiping (2002 – 2004), Sekolah Kebangsaan Rapat Setia in Ipoh (2005) and Sekolah Kebangsaan Wangsa Melawati in Kuala Lumpur (2006 – 2007). Furthermore, the author had been to Sekolah Menengah Kebangsaan Aminuddin Baki in Kuala Lumpur for high school studies from 2008 to 2012. Pursue foundation study in pure science at Kolej Matrikulasi Pahang (KMPh) in year 2013 to 2014. She holds Bachelor of Engineering (Electrical and Electronics) from Universiti Putra Malaysia (UPM) in 2018. Lastly, pursuing Master of Science in Electrical Engineering in UPM from 2018 until 2021.

LIST OF PUBLICATIONS

Journal

Norhisam Misron, **Nisa Syakirah Kamal Azhar**, Mohd Nizar Hamidon, Ishak Aris, Kunihisa Tashiro and Hirokazu Nagata, "Fruit Battery with Charging Concept for Oil Palm Maturity Sensor", *Sensors* in Agriculture 2019, *Sensors (Switzerland)*, vol. 20, issue 1 (Impact Factor : Q1)

Norhisam Misron, **Nisa Syakirah Kamal Azhar**, Mohd Nizar Hamidon, Ishak Aris, Kunihisa Tashiro and Hirokazu Nagata, "Effect of Charging Parameter on Fruit Battery-Based Oil Palm Maturity Sensor", Micromachines, vol. 11, issue 806 (Impact Factor : Q2)

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