UNIVERSITI PUTRA MALAYSIA

DEVELOPMENT OF 3 DIMENSIONAL POINT CLOUD ANALYSIS TECHNIQUE TO DETERMINE MATURITY OF OIL PALM FRESH FRUIT BUNCH BASED ON FROND POSITION IN OIL PALM PHYLLOTAXIS

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FK 2018 118

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By

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

July 2018

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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A major challenge in oil palm industry is the shortage of labour mainly in harvesting operation. Harvesting operation accounts for 85% of total labour cost for oil palm sector showing that it is the crucial part of the operation in oil palm industry. Oil palm FFB need to be harvested at the right stage of ripeness to ensure optimum oil quality and quantity. Harvesters normally uses their experience in searching for loose fruits on the ground and observing the oil palm FFB's color as an indication of matured bunch. In the early stage of this research, a new method to determine maturity stages of oil palm FFB based on its position in oil palm phyllotaxis frond spiral is verified. A formula to determine estimated harvesting date oil palm FFB called "Maturity Model" is derived based on the information of rate of frond production per month (RFP), duration of oil palm FFB development from anthesis (DOFFB) and position of oil palm FFB in frond spiral (FFBPFS). Oil palm FFB samples position in frond spiral is identified for harvesting date estimation and the FFB sample is monitored up to the harvesting day. In-field oil palm FFB sample date of harvest by farmers was compared with the estimated harvesting date calculated based on its position in frond spiral for validation. Regression analysis between Maturity Model estimated harvesting week and actual in-field harvesting week gives the coefficient of determination R2 = 0.90 and root mean square error (RMSE) of 1.58 weeks. From the result, the new method of determining maturity stages of oil palm FFB based on its position in frond spiral showed a positive outcome. Automatic approach to determine maturity based on frond position in Fibonacci phylloyaxis was introduced by using a 3D point cloud approach. The terrestrial LiDAR laser scanner (FARO Focus 3D 120) was used to acquire 3D point cloud data in order form a surface representation of oil palm tree. A Point Cloud Analyzation (PCLA) model was developed by using MATLAB application to analyze the characteristic of the oil palm tree. The PCLA model is able to identify the trunk diameter, spiral arrangement, total number of frond, label frond number based on phyllotaxis and determine the coordinate of each frond in world coordinate. Labelling frond number based on phyllotaxis is done based on tree height from the ground and then rectified using the Fibonacci phyllotaxis angle. PCLA model gives 76% accuracy for identification of frond spiral arrangement and coefficient of determination (R2) equal to 0.78 for identification total number of frond. A method to determine oil palm FFB was developed based on the height distribution of the fronds. Non-linear frond height distribution of the frond is a sign for the presence of the oil palm FFB. This is a potential new method of detecting the presence of oil palm FFB as well as the maturity stages. The outcome of this research will be helpful as a starter for a fully automated process to determine oil palm FFB maturity stages.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah sarjana sains

PEMBANGUNAN TEKNIK MENGANALISA POINT CLOUD 3 DIMENSI UNTUK MENENTUKAN TAHAP KEMATANGAN BUAH KELAPA SAWIT BERDASARKAN KEDUDUKAN DAHAN PADA PHYLLOTAXIS

Oleh

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Cabaran utama dalam industri kelapa sawit adalah kekurangan tenaga pekerja terutamanya dalam operasi menuai. Operasi menuai memperuntukkan sebanyak 85% daripada keseluruhan jumlah kos buruh untuk sektor kelapa sawit menunjukkan bahawa ia adalah bahagian yang penting dalam industry kelapa sawit. Tandan buah (FFB) kelapa sawit perlu dituai pada tahap kematangan yang tepat untuk memastikan kualiti dan kuantiti minyak yang optimum. Pekerja ladang biasanya menggunakan pengalaman mereka dalam mencari leraian buah kelapa sawit di atas tanah dan memerhati warna tandan kelapa sawit sebagai petunjuk menentukan tandan matang. Pada peringkat awal penyelidikan, kaedah baru untuk menentukan tahap kematangan tandan kelapa sawit berdasarkan kedudukan tandan tersebut dalam lingkaran dahan phyllotaxis perlu disahkan terlebih dahulu. Formula untuk menentukan anggaran tarikh penuaian FFB yang dipanggil “Model Kematangan” diperolehi berdasarkan maklumat kadar pengeluaran dahan setiap bulan (RFP), tempoh perkembangan tandan kelapa sawit daripada pendebungaan (DOFFB) dan kedudukan tandan kelapa sawit pada dahan (FFBPFS). Kedudukan sampel tandan kelapa sawit pada dahan telah dikenal pasti untuk anggaran tarikh penuaian dan sampel tandan kelapa sawit dipantau sehingga hari penuaian oleh pekerja ladang. Tarikh penuaian sampel FFB kelapa sawit yang dilakukan oleh pekerja ladang dibandingkan dengan tarikh penuaian yang dianggarkan berdasarkan posisi pada dahan, bagi tujuan pengesahan. Analisis regrasi antara anggaran minggu penuaian FFB kelapa sawit dan minggu penuaian FFB kelapa sawit yang dilakukan oleh pekerja ladang memberikan pekali penentuan (R2) = 0.90 dan ralat min kuasa dua (RMSE) sebanyak 1.58 minggu. Berdasarkan hasil kajian tersebut mendapati kaedah baru bagi menentukan kematangan FFB kelapa sawit berdasarkan posisi pada dahan boleh diguna pakai. Pendekatan automatic untuk menentukan kematangan berdasarkan kedudukan dahan pada phyllotaxis Fibonacci diperkenalkan dengan menggunakan kaedah ‘point cloud’ 3D. ‘Terrestrial LiDAR (FARO Focus 3D 120)’ digunakan untuk memperoleh data ‘point cloud’ 3D untuk membentuk permukaan pokok kelapa sawit. Model penganalisa ‘point cloud’ (PCLA) telahpun dibangunkan dengan menggunakan aplikasi MATLAB untuk menganalisa bentuk dan ciri-ciri pokok kelapa sawit. Model PCLA dapat mengenal pasti diameter batang pokok kelapa sawit, susunan lingkaran dahan, jumlah dahan, melabel nombor dahan berdasarkan phyllotaxis fibonacci dan menentukan lokasi setiap dahan dalam sistem koordinat. Pelabelan nombor dahan berdasarkan phyllotaxis dilakukan dengan menggunakan ciri ketinggian dahan daripada tanah dan kemudian dibetulkan semula menggunakan sudut phyllotaxis fibonacci sekira adanya kesilapan. Model PCLA memberikan jumlah ketepatan sebanyak 76% bagi penentuan susunan lingkaran dahan dan pekali penentuan (R2) sebanyak 0.78 bagi penentuan jumlah dahan. Kaedah untuk menentukan kehadiran tandan kelapa sawit ditemui berdasarkan ciri ketinggian setiap dahan kelapa sawit. Ketinggian dahan yang tidak linear di antara dahan yang lain mempunyai potensi untuk mempunyai FFB kelapa sawit pada dahan tersebut. Ini adalah kemungkinan kaedah baru untuk menentukan kehadiran FFB kelapa sawit pada dahan dan sekaligus dapat mengenalpasti tahap kematangan FFB kelapa sawit tersebut. Hasil daripada penyelidikan ini akan dapat membantu bagi peringkat pemulaan kepada proses penentuan tahap kematangan FFB kelapa sawit secara automatik.

ACKNOWLEDGEMENTS

Firstly, I'm grateful to Allah The Almighty God for establishing me to complete this thesis. I would like to express my profound gratitude and deep regards to my supervisor, Dr. Muhamad Saufi Mohd Kassim for the opportunity by selecting among others to complete this research work. Thank you for the close attention throughout my studies, constant encouragement, blessing, help, and guidance in this long journey of research.

I also take this opportunity to express a gratitude to my co-supervisory committee, Dr. Ahmad Fikri Abdullah and Dr. Hazreen Haizi Harith for a valuable information, guidance, and support throughout this research. Knowledge and expertise in their field really helpful in completing my research. I would like to thank and appreciate Universiti Putra Malaysia (UPM) Kampus Serdang for providing research grant and allowing me to conduct my study in the UPM Oil Palm plantation. I would like to express my appreciation to every staff in Department of Biological and Agricultural Engineering UPM, for their help and assisting me during fieldwork.

Last but not least, special thanks to my family members especially my parents and brothers. Thank you for supporting me at the very beginning, patience, and prayers.

I certify that a Thesis Examination Committee has met on 4 July 2018 to conduct the final examination of Zulfadhli bin Mustafa Albakri on his thesis entitled "Development of 3 Dimensional Point Cloud Analysis Technique to Determine Maturity of Oil Palm Fresh Fruit Bunch Based on Frond Position in Oil Palm Phyllotaxis" in accordance with the 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 student be awarded the Master of Science.

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CHAPTER 1

INTRODUCTION

1.1 General Overview

Malaysia is known as the world's second largest producer of oil palm behind Indonesia followed by Nigeria, Thailand, and Columbia. Malaysia's oil palm export industry gives a major contribution to the government profit (Basiron, 2007). Five million hectares of Malaysia's land is covered up with oil palm crop (Hazir, Shariff, & Amiruddin, 2012). Harvesting process is one of the most crucial processes in oil palm industry. Production of oil palm fresh fruit bunch (FFB) yield depends on the strategy of harvesting. Oil palm FFB yield is a common parameter to measure the productivity and the most results had verified and confirmed at post harvesting level (Kassim, Ismail, Ramli, & Bejo, 2012). Labor, machinery requirement, monetary budget, oil palm mill capacity and various oil palm plantation management aspects can be planned if they have the accurate yield estimation (Kassim, Ismail, Ramli, & Bejo, 2012).

The critical issue in harvesting oil palm FFB is to harvest at the right stage of ripeness to ensure the maximum quantity and quality of palm oil during extraction process at the mill (Ishak & Hudzari, 2010; Rajanaidu, Abdul, Wood, & Sarjit, 1988). Oil palm FFB grading defines a ripe bunch when the mesocarp has 10 or more empty sockets of detached fruitlets, which under-ripe bunch has less than 10 empty sockets and an unripe-bunch has no empty sockets (MPOIP, 2008). In the field, optimum oil palm FFB maturity determination based on plantation standard operation procedure (SOP) is determined by identifying the tree with loose fruit and then observing the color of the bunch. A drop of just one fruitlet showing the oil palm FFB is already matured (Kassim, Ismail, Ramli, & Bejo, 2012; Ghani, Zakaria, & Wahid, 2004). An under-ripe bunch appears blackish purple whereas a ripe bunch appears reddish orange (Ismail & Razali, 2012). Most of the plantation use scheduling system for harvesting operation. Normally the harvester will harvest on particular site once in a one to two weeks' interval. A sickle attached to a bamboo or aluminum pole over 12 meter height, or a chisel for shorter palm is carried by harvester during the harvesting operation (Azhar, Norhisam, Wakiwaka, Tashiro, & Nirei, 2012).During each cycle of harvesting, the harvester will move from one tree to another searching for the matured oil palm FFB based on their knowledge and previous experience. Sometimes, the harvesting schedule caused them to harvest the over-ripe FFB causing lots of loose fruit fall on the ground. According to Sime Darby Plantation, almost RM11 million lost in their annual income for every uncollected loose fruit per tree for a total of 500,000 hectares planted area (Kassim, Ismail, Ramli, & Bejo, 2012; Sime Darby, 2008).

In order to improve the situation, many research has been done to estimate the maturity stages of oil palm FFB either unharvested or harvested. Common features used by the researcher is by analyzing the oil palm FFB color. However, not all varieties of oil palm have the same characteristic of color to define maturity of oil palm FFB. The color feature also has a limitation mainly due to the varied light intensity condition. Therefore, additional features need to be explored to determine maturity stages of oil palm FFB in order support the decision making based on the color feature. Besides oil palm maturity, black bunch counting is also important for oil palm plantation to estimate the oil palm yield. The current method of bunch counting is laborious. Thus, the need for oil palm FFB maturity determination system is crucial to improve its productivity and moving towards site specific harvesting in oil palm industry.

1.2 Problem Statement

Currently, oil palm plantation does not have early detection method to estimate the volume of matured bunch in particular area apart from manual counting method. Harvester will have to go through all the trees one by one searching for the matured oil palm FFB. This operation is tedious and because of this, they create a harvesting cycle which causes them to harvest an under-ripe and over-ripe bunch. Available information on estimated yield production and exact location of the tree with matured bunch will be useful to perform precise oil palm harvesting operation. Farmers can schedule and execute their workers together with the required machine for transportation purpose. Yield estimation per week makes it easy for the plantation to estimate their harvester's pay (Kassim, Ismail, Ramli, & Bejo, 2012; Gan, Heng, & Goh, 2001).

A common model of oil palm FFB maturity determination is based on oil palm FFB color changes as unripe oil palm FFB is usually blackish purple in color and turns into reddish brown during ripening. However, the method using the color feature to determine the maturity stage has caused some doubt among the experienced plantation managers. This is because the color of oil palm FFB is not always constant and it will vary depending on the different type of oil palm variety, weather changes, oil palm tree management and many others. New features of determining the oil palm FFB maturity that can speed up the process in large scale need to be explored in addition to color features. Most ideal features usually can be found by going back to the oil palm agronomy itself. Oil palm frond has equal potential to produce oil palm FFB starting with pollination phase. Well maintained oil palm tree will have a bunch on every frond after the pollination phase. Trees without oil palm FFB most probably have lack of maintenance on the water level, fertilizer, and diseases. Oil palm tree has phyllotaxis type of frond. Based on the oil palm tree agronomy information such as rate of frond production per month (three frond per month for less than seven years old and two new frond per month for more than seven years old), duration of FFB development after anthesis (6 month or 180 days), initiation of anthesis at the particular frond (20^{th} frond), and location of oil palm FFB in frond number (X^{th} frond), the maturity stages of oil palm FFB can be identified. To further improve this new method, terrestrial LiDAR scanner (TLS) is used to capture 3D point cloud data of oil palm tree. Point cloud analyzation (PCLA) model is developed to analyze the 3D point cloud data in order to identify valuable information from the oil palm tree.

1.3 Objectives

In order to explore the capability of terrestrial LiDAR scanner (TLS) to determine the maturity stages of oil palm FFB, the following objectives were carried out throughout this research:

i. Verification of method to determine maturity stages of oil palm FFB based on its position in frond spiral.

ii. Development of oil palm tree 3D point cloud segmentation method to extract frond features.

iii. Development of a technique to analyze 3D point cloud geometrical properties to identify frond position in frond spiral and the presence of oil palm FFB.

1.4 Scope of Study

In this research, a new method is proposed to determine the maturity stages of oil palm FFB based on its position in frond spiral. Other aspect such as weather, verities, water volume and temperature is considered as constant. Proposed method maturity determination is only using the agronomy position of oil palm FFB on frond spiral only. 30 trees consisting of 63 oil palm FFB at Ladang 15 UPM Serdang were monitored for maturity model validation purpose. Maturity model verification is based on the farmer's judgement. Harvested FFB date is recorded to compare with the maturity model estimation. There is no laboratory test to confirm the ripeness of the harvested FFB. Farmer's judgement is mainly focus on the loose fruit on the ground and color changes of the oil palm FFB. Developed point cloud analyzation (PCLA) model for the 3D data enable user to identify the coordinate position of the desired frond number and specify the frond number which has oil palm FFB. Point cloud analyzation (PCLA) model is develop based on oil palm tree geometrical properties only with using the features of coordinate (X, Y and Z) and angle between point cloud. Information of color (R, G and B) also captured during the TLS data collection, but did not used for the PCLA model analysis in this research. Point cloud analyzation (PCLA) model only able to gives automatic result for center detection, spiral arrangement identification and frond counting. Numbering frond and bunch detection is done manually.

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