UNIVERSITI PUTRA MALAYSIA

IMAGE BASED OIL PALM FRUIT BUNCH GROWTH MODELING FOR HARVESTING OPERATION

MUHAMAD SAUFI MOHD KASSIM

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By

MUHAMAD SAUFI MOHD KASSIM

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

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DEDICATION

This thesis is dedicated to my families who have supported me all the way since the beginning of my studies.

Also, this thesis is dedicated to my wife and our Children who has been a great source of motivation and inspiration.

Finally, this thesis is dedicated to all those who have given their support during my studies.

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirement for the degree of Doctor of Philosophy

IMAGE BASED GROWTH MODELING OF OIL PALM FRESH FRUIT BUNCH FOR HARVESTING OPERATION

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MUHAMAD SAUFI MOHD KASSIM

June 2013

Chairman: Professor Wan Ishak Wan Ismail, PhD

Institute: Institute of Advanced Technology

Oil Palm Fresh Fruit Bunch (FFB) need to be harvested at the optimum maturity stage to optimize the quality of palm oil. Currently the oil palm harvester determines the FFB maturity based on natural indicators such as FFB color appearance and number of FFB loose fruit drops under the tree. During executing the harvesting operation the harvester need to search for a ripe FFB and at the same time carrying the harvesting pole. Tedious harvesting operation degrades the consistency of their judgment. The harvested FFB must be graded at the oil palm mill to separate into groups of maturity level according to the standard. In this research, the development of FFB from the anthesis to harvesting stage was monitored by using a handy digital camera over a period of eight months. A computer application called Growth Table was developed to manage the FFB digital images and ease the process of grouping the digital images into 25 groups of FFB maturity stages. The digital images of the FFB were processed by using digital image processing techniques to

extract the color information that represent the maturity stages. Two types of color spaces were investigated, HSV(Hue, Saturation and Value) and RGB (Red, Green and Blue) color space. In HSV color space only Hue component was considered to extract maturity information. During the process, a clustering technique was used to separate every single FFB image into three color clusters that represent three FFB features which were Fruitlet, Brown Spine and Green spine. As a result from the analysed image information and tabulated data in Growth Table, a relationship of FFB features color changing and maturity stages were investigated. The Growth Model of the above relationship was developed. During the process it was found that the FFB grow in stages. In Hue color component, the FFB was found to grow in three major stages. First Major Growth Stages(hue) (FMGSh) was from week 0 to 5, Second Major Growth Stages(hue) (SGMSh) was from week 5 to 14 and Third Major Growth Stages(hue) (TMGSh) from week 15 to 24. FFB development in RGB color space was found to have two major growth stages. First Major Growth Stages (FMGS) from week 0 to 5 and Second Major Growth Stages (SMGS) were from week 6 to 24. From the regression analysis, linear models and multiple linear models of each major growth stages was determined to develop the Growth Models. Predicted maturity stages data using the developed Growth Models were validated with the actual maturity stage as determined by using the Growth Table. In term of the accuracies of predicted data as compared with the actual data, the best Hue model had an R^2= 0.95 for the third growth stage while the best RGB model had an R^2= 0.9 for first growth stage. The processed information by using the developed Growth Model also enables the development of FFB Harvesting Model. The data from Harvesting Model can be used to generate a graphical oil palm leaf spiral that mapped the location of FFB in relation with the location of oil palm leaves. FFB production can be monitored by observing the presence of FFB at oil palm 17th leaves position that is the beginning of anthesis phase to oil palm leaves at 32nd where FFB is at optimum maturity stage. A GIS map displaying the location of matured FFB on the tree and the maturity stages of the FFB can be generated. The GIS map can be used as a support system in site specific harvesting operation. This Harvesting Model enables site specific harvesting at optimum maturity stage, overcome losses due to uncollected loose fruits. Growth Model has a potential to eliminate FFB screening process at oil palm mill level. Harvesting Model can be a tool of choice for better harvesting scheduling and can be a good tool to predict FFB yield. The developed models from this research have a high potential to improve oil palm field management as well as oil palm mill.

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

PEMODELAN TUMBESARAN BUAH TANDAN SEGAR KELAPA SAWIT BERASASKAN IMEJNYA UNTUK OPERASI PENUAIAN

Oleh

MUHAMAD SAUFI MOHD KASSIM

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Buan Tandan Segar (BTS) perlu dituai ketika peringkat kematangan yang optimum untuk mendapatkan minyak sawit yang berkualiti. Buat masa ini penuai menentukan kematangan BTS berdasarkan petunjuk semulajadi BTS seperti penampilan warnanya juga bilangan buah lerai yang jatuh di bawah pokok sawit. Semasa menjalankan operasi penuaian, penuai perlu mencari BTS yang matang sambil memikul galah pemotong. Operasi penuaian yang memenatkan mengurangkan keupayaan membuat penakulan yang baik. Hasil tuaian BTS perlu disisih di kilang kelapa sawit untuk memisahkannya kepada peringkat kematangan yang mematuhi piawai. Penyelidikan ini memantau perkembangan BTS dari peringkat ia mengorak sehingga peringkat penuaian dengan penggunaan kamera digital sepanjang tempoh lapan bulan. Aplikasi komputer yang dinamakan Jadual Tumbesaran telah dibangunkan untuk tujuan mengurus imej-imej digital BTS. Ini memudahkan proses penyisihan imej-imej digital tersebut kepada 25 kumpulan yang mewakili peringkat-peringkat kematangan BTS. Imej-imej digital BTS ini telah diproses menggunakan

teknik-teknik pemprosesan imej digital untuk mengenalpasti maklumat yang terkandung di dalam warnanya yang boleh dikaitkan dengan peringkat kematangannya. Dua jenis ruang warna yang telah dikajiselidik, iaitu HSV (Hue, Saturation dan Value) dan RGB (Red, Green dan Blue). Bagi ruang warna HSV hanya kompisisi Hue yang diambil kira untuk mendapatkan maklumat kematangan. Di dalam kajiselidik teknik pengelompokan telah digunapakai untuk memisahkan setiap imej BTS kepada tiga kelompok warna yang mewakili tiga ciri BTS iaitu Buah, Tetulang perang dan Tetulang hijau. Dari hasil analisa terhadap maklumat imej serta data yang terjadual di dalam Jadual Tumbesaran, hubungan diantara perubahan warna ciri-ciri BTS dan peringkat kematangan boleh dikajiselidik. Model Tumbesaran hubungan tersebut dapat dibina. Di dalam kajiselidik di dapati BTS membesar secara berperingkat. Dalam komposisi warna Hue, BTS didapati membesar dalam tiga fasa utama . Fasa Pertama Peringkat Tumbesaran(hue) (FMGSh) bermula dari minggu 0 hingga 5, Fasa Kedua Peringkat Tumbesaran(hue) (SMGSh) bermula dari minggu 6 hingga 14 dan Fasa Ketiga Peringkat Tumbesaran (TMGSh) bermula dari minggu 15 hingga 24. Perkembangan BTS dalam komposisi warna RGB didapati mempunyai dua fasa utama. Fasa Pertama Peringkat Tumbesaran (FMGS) bermula dari minggu 0 hingga 5 dan Fasa Kedua Peringkat Tumbesaran (SMGS) bermula dari minggu 6 hingga 24. Dari analisa regrasi model linear dan juga model linear berbilang untuk setiap fasa tumbesaran ditentukan untuk menghasilkan Model Tumbesaran. Data peringkat kematangan yang di ramal menggunakan Model Tumbesaran yang dibangunkan, ditentusahkan dengan data sebenar dari hasil penentuan menggunakan Jadual Tumbesaran. Dari segi kejituan data ramalan jika dibandingkan dengan data sebenar, model komposisi warna Hue yang terbaik mempunyai R^2=0.95 untuk fasa ketiga sementara ruang warna RGB yang terbaik mempunyai R^2=0.9 untuk fasa pertama. Maklumat yang telah diproses menggunakan Model Tumbesaran yang telah dibangunkan membolehkan pembangunan Model Penuaian BTS. Data dari Model Penuaian pula boleh digunakan untuk menghasilkan grafik lingkar pusar daun kelapa sawit yang memetakan lokasi BTS kepada daun yang bersesuaian di dalam lingkar pusar tersebut. Penghasilan BTS boleh dipantau melalui pemerhatian terhadap kehadiran BTS pada daun ke 17 kelapa sawit tempat bermulanya proses mengorak hingga ke kedudukan daun kelapa sawit ke 32 di mana BTS matang berada. Peta GIS yang memaparkan lokasi BTS yang matang pada sesuatu pokok dan juga peringkat-peringkat kematangan BTS boleh dihasilkan. Peta GIS ini boleh digunakan sebagai sistem sokongan kepada operasi penuaian tentu tapak. Model Penuaian membolehkan penuaian tentu tapak dilakukan pada kadar kematangan BTS yang optimum, mengurangkan kerugian atas buah lerai yang tidak dikutip. Model Tumbesaran pula mempunyai potensi untuk melangkaui process penyaringan di peringkat kilang kelapa sawit. Model Penuaian berupaya menjadi perkakas utama kepada penghasilan jadual penuaian yang lebih tersusun, juga perkakas yang baik untuk meramal hasil pengeluaran BTS. Model-model yang dibangunakan dari kajiselidik ini mempunyai potensi besar untuk menambahbaik pengurusan ladang juga kilang kelapa sawit

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I certify that an Examination Committee has met on 11 June 2013 to conduct the final examination of Muhamad Saufi Mohd Kassim on his thesis entitled "Image Based Oil Palm Fruit Bunch Growth Modeling for Harvesting Operation" 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 Doctor of Philosophy.

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This thesis was submitted to the Senate of Universiti Putra Malaysia 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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DECLARATION

I declare that the thesis is based on my original work except for quotations and citations, which have been duly acknowledged. I also declare that it has not been previously, and is not concurrently submitted for any other degree at Universiti Putra Malaysia or other institutions.

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MUHAMAD SAUFI MOHD KASSIM

Date: 11 June 2013

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LIST OF ABBREVIATIONS

AMS	Actual Maturity Stage
BS	Blunt Spine
BSB	Blunt Spine in Blue
BSG	Blunt Spine in Green
BSM	Blunt Spine Model
BSR	Blunt Spine in Red
DOA	Date of Acquisition
DOFFBD	Days of FFB Development
DOH	Date Of Harvest
FFB	Fresh Fruit Bunch
FFBPLS	FFB Position in Leaf Spiral
FMGS	First Major Growth Stages
FMGSh	First Major Growth Stages(hue)
FT	Fruitlet
FTB	Fruitlet in Blue
FTG	Fruitlet in Green
FTM	Fruitlet Model
FTR	Fruitlet in Red
GIS	Geographical Information System
GPS	Global Positioning System
GROS	Graphical Oil Palm Leaf Spiral
GS	Green Spine

GSB	Green Spine in Blue
GSG	Green Spine in Green
GSM	Green Spine Model
GSR	Green Spine in Red
GT	Growth Table
GUI	Graphical User Interface
HSI	Hue, Saturation and Intensity
HSV	Hue, Saturation and Value
IIC	Image Input Components
IPC	Image Processing Component
MLRBS	Multiple Linear Regression for Blunt Spine
MLRFT	Multiple Linear Regression for Fruitlet
MLRGS	Multiple Linear Regression for Green Spine
MPOB	Malaysian Palm Oil Board
OVC	Output Viewer Component
PMS	Predicted Maturity Stage
RGB	Red, Green and Blue
SMGS	Second Major Growth Stages
SMGSh	Second Major Growth Stages(hue)
TMGS	Third Major Growth Stages
TMGSh	Third Major Growth Stages(hue)

CHAPTER 1

INTRODUCTION

1.1 General Overview.

Oil Palm (*Elaeis guineensis* Jacq var. Tenera) is one of the most important plantation crops in Malaysia. Oil Palm Fresh Fruit Bunch(FFB) harvesting and collection form a single largest direct cost in the production of oil palm(Gan et al., 1993;Omereji, 1991). FFB yield is a common parameter to measure the productivity and most resultshad verified and confirmed at post harvesting level.Accurate yield estimation will be very useful to plan labor and machinery requirement, monetary budget, oil palm mill capacity and various oil palm plantation management aspects.

New trend of agricultural practices and agricultural consumer demand required early information on yield and quality of the agricultural product.Harvesting Oil Palm FFB at right stage of ripeness is critical to ensuring optimum quality and quantity of oil production and thus profitability to the industry(Rajanaidu, et al., 1988). In order to maximize the oil extraction rate, the FFB should be harvested at its peak of ripeness (Ariffin, 1984).Currently loose fruitlet is the indicator to harvest the FFB. According to Ghani et al., (2004) if the FFB dropped just one fruitlet, the bunch is at the optimum maturity stage. In the standard operating procedure, matured FFB is highly related with number of loose fruits drop under the oil palm tree(Ghani et al., 2004). This loose fruit is use as a sign to harvest the FFB and has a drawback because uncollected loose fruit is one of the factors contributed to the losses in Malaysia oil palm industries. Sime Darby Plantation, one of the biggest oil palm plantation in

Malaysia, reported the company potentially lost almost RM11 million in annual income if only one uncollected loose fruit per tree per total of 500,000 hectares planted area (Sime Darby, 2008). Further increased of loose fruit per bunch leads to higher field losses (Gan et al., 1993). A new kind of monitoring system is required to determine maturity stages of oil palm to avoid losses due to loose fruit (Osborne et al., 1992; Ghani et al., 2004). Various techniques have been developed to measure the maturity stages of FFB. Three parameters commonly used to measure the maturity of FFB are color, fruitlets moisture content and oil content. Out of the three parameters, FFB color is the best choice in developing the new FFB maturity stages determination since it is non-destructive method. And less complex laboratory procedure as compare to determination of FFB maturity stage based on moisture and oil content. FFB Maturity stage, number of matured FFB per tree and per harvesting cycle and location of the tree with matured FFB are very important information. This information is essential to the management at the harvesting time to ease the harvesting operation. This information is also useful for yield forecasting and crop management. Farmer or plantation manager can use this information to manage their workers, machines and other agricultural resources to increase productivity. These decision are critical, must be carefully made with full information and knowledge of the oil palm condition (Gan et al., 2001). All this depend on the quality and reliability of the input information. Figure 1 shows the schematic diagram of harvesting operation procedure. During executing the harvesting operation the harvester will carry a sickle attached to bamboo or aluminum pole for palm tree over 12m height and chisel for shorter palm. Currently, many estates used ‘Cantas’ a mechanical harvester to harvest the FFB. They will move to each tree searching for ripe fruit (including tree without ripe FFB) and used their own experience to guess the maturity stage based on the natural indicators, the loose fruit on the ground and the color of the FFB. Once they detected the ripe bunch the leaf that subtended the bunch will be cut in order to expose the bunch to have a clear view for positioning the cutting tool. Once the bunch is harvest the fallen leaf will be arrange in between the row. It is a standard procedure to manage the leaves decomposition andfor better in field machine traversable route. Time consumed process in searching for matured FFB and tedious harvesting task force them to lose their judgment, consistency and concentration. Thus the need FFB maturity determination system and information towards site specific harvesting are crucial.

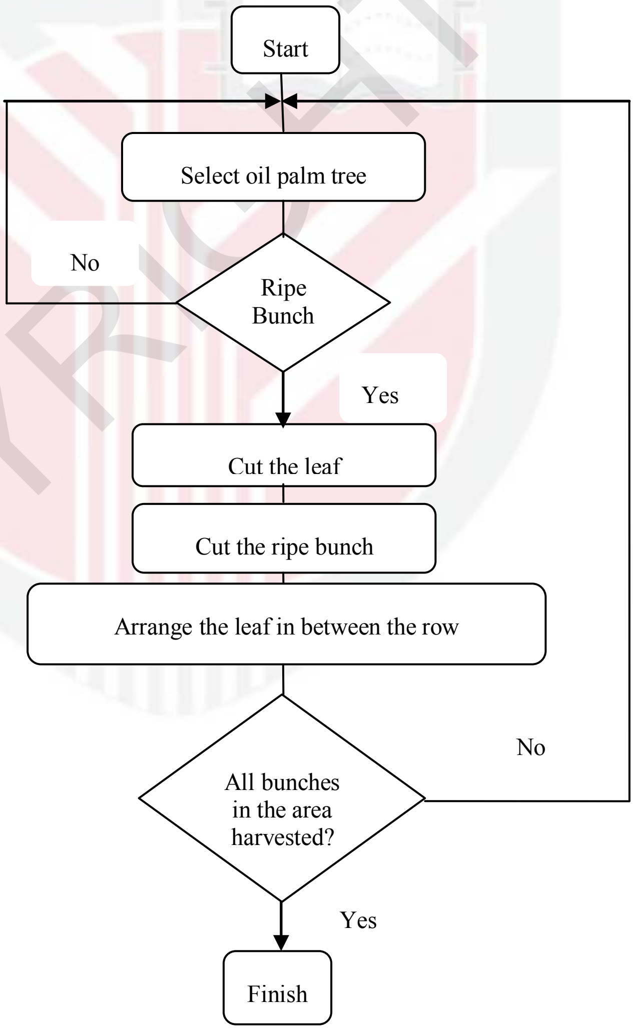

Figure 1: Schematic Diagram of harvesting operation procedure.

1.2 Statements of Problems

In every cycle of harvesting operation, farmer does not have any information on how many matured bunches and which oil palm tree will be harvested. Their task will be easy if they know the exact location of the ripe FFB. A reliable FFB maturity stage determination system and its specific location will be very useful towards better oil palm crop management system especially in harvesting operation to overcome losses due to uncollected loose fruit and low oil quality due to accumulation of free fatty acid in over ripe bunch. Developed FFB maturity determination (Junkwon et al., 2009;Alfatni et al., 2008; Abbas et al., 2005; Idris et al., 2003)was meant for harvested bunch. In order to develop a system for site specific harvesting, a system must be developed to determine; the available FFB on the tree for yield recording, the maturity stages and the harvesting date to schedule the future harvesting operation and the position of the tree for site specific harvesting.

Availability of this information enables effective work force management at every harvesting cycle. Farmer can schedule and execute site specific harvesting effectively if they know the exact location of ripe FFB. Worker salary per harvested bunch and total count of bunches can be easily projected before completing the task and yield for every harvesting cycle easily justified after completing the harvesting operation. FFB weight and total number of bunches are two major parameters used to determine the harvester's pay in oil palm estates and it is therefore important to get them correct (Ganet al., 2001).

The need of such information motivates us to develop models that can provide farmers the needed information. Digital imaging is the choice to develop such system, since digital image can provide the needed information. Digital Imaging was widely used to inspect the quality of the biological product mostly dealing with a single color biological product as carried out by Lu, R. (2003); Peng, Y., & Lu, R. (2007) and ElMasry, G., et al (2008) for Apple to determine the firmness, soluble solids content and bruises detection. Gaffney, J.J. (1969); Jimenez-Cuesta et al.,(1981); Harrel et al., (1985); Gómez-Sanchis, J., et al (2008) and Okamoto, H., & Lee, W. S. (2009) carried out research to determine maturity stage, grading and diseases in Citrus. For tomatoes research were carried out by Choi et al., (1995) and Polder, et al (2002) to determine the maturity.

In order to increase the efficiency, researcher requires high accuracy equipments. This will increase the equipment cost and more complex imaging system. Most of the equipments were meant for indoor environment. Oil palm FFB inspection need to be carried out at plantation environment by using handy, less complex and affordable cost equipments. Oil Palm FFB is a multi-color agricultural product, a color separation and recognition technique need to be carried out to identify the most significant colors features to develop the models to determine the FFB maturity stages.

1.3 Objectives

The main objective of this research is to develop and validate a computer model to monitor the growing stages of the FFB in order to reduce the losses due to improper field management practice especially during harvesting operation. The following objectives were carried out:

i. Development of FFB Growth Table, based on the information acquired from the images of FFB development towards maturity.
ii. Development and validation of Growth Model to determine FFB maturity stages and it's fruiting pattern.
iii. Development of Harvesting Model for harvesting scheduling and site specific harvesting.
iv. Development of FFB Yield Model based on FFB fruiting pattern and Harvesting Model data.

1.4 Scope of the study

In this research a growth model to predict the FFB maturity stages will be developed based on the information convey by digital images of the FFB from the early FFB development at anthesis stage until the day of harvesting. The growth model will be developed to measure the growth performance by determining the fruiting cycle and leaf production rate. A harvesting model to support efficient harvesting operation will then develop based on the information from growth model. The models are expected to determine the harvesting date of particular FFB for a particular oil palm tree and the projection of the expected FFB yield of the particular oil palm tree.

In this research, the models will be developed based on the following inputs; information about color appearance of the available FFB on the tree, the position of the FFB in relation with oil palm leaf and the rate of oil palm leaves production per month. A digital camera will be used as imaging device to capture the images of oil palm FFB from anthesis stage to the harvesting stage. Based on the agronomy aspect and color information extracted from the FFB images, a growth model, harvesting model and yield model will be developed. Growth model is used to predict the maturity stages for the FFB based on the variation of FFB color. Once the maturity stages of the FFB are determined, the information will be used to develop the harvesting model to determine the harvesting date of the available FFB on the particular tree. The expected output from the harvesting model will be a site specific harvesting data. Based on information from harvesting model, a harvesting schedule can be developed. In the harvesting model, any available FFB on the particular tree will be mapped into the graphical leaf spiral representation. This can be used to measure and predict the growth performance of the oil palm tree in term of producing the FFB. Any present or absence of oil palm FFB in the graphical leaf spiral representation can be relate to field management practices such as fertilizing frequency and availability of water, and the effect of climatic changes that influence the fruiting pattern.

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LIST OF PUBLICATIONS

Journal

1. **Muhamad Saufi Mohd Kassim,** Wan Ishak Wan Ismail , Abdul Rahman Ramli and Siti Khairunniza Bejo.(2012).Oil palm fresh fruit bunches (FFB) growth determination system to support harvesting operation. Journal of Food, Agriculture & Environment Vol.10 (2) : 620-625.2012

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