MULTI SENSOR SYSTEM FOR CLASSIFYING HARUMANIS MANGO BASED ON EXTERNAL AND INTERNAL QUALITY

MOHD FIRDAUS IBRAHIM

UNIVERSITI MALAYSIA PERLIS
2016

Multi Sensor System for Classifying Harumanis Mango Based on External and Internal Quality

by

Mohd Firdaus Ibrahim
(1430611364)

A thesis submitted in fulfilment of the requirements for the degree of
Master of Science in Mechatronic Engineering

School of Mechatronic Engineering
UNIVERSITI MALAYSIA PERLIS

2016

THESIS DECLARATION

Author's full name : MOHD FIRDAUS IBRAHIM

Date of birth : 27 MARCH 1990

Title : MULTI SENSOR SYSTEM FOR CLASSIFYING HARUMANIS MANGO BASED ON EXTERNAL AND INTERNAL QUALITY

Academic Session : 2014 - 2016

I hereby declare that this thesis becomes the property of Universiti Malaysia Perlis (UniMAP) and to be placed at the library of UniMAP. This thesis is classified as:

☐	**CONFIDENTIAL**	(Contains confidential information under the Official Secret Act 1972)
☐	**RESTRICTED**	(Contains restricted information as specified by the organization where research was done)
☑	**OPEN ACCESS**	I agree that my thesis is to be made immediately available as hard copy or online open access (full text)

I, the author, give permission to the UniMAP to reproduce this thesis in whole or in part for the purpose of research or academic exchange only (except during a period of _____ years, if so requested above).

Certified by:

SIGNATURE

900327-01-6535

(NEW IC NO. /PASSPORT NO.)

Date: 19 APRIL 2017

SIGNATURE OF SUPERVISOR

DR. AMMAR ZAKARIA

NAME OF SUPERVISOR

Date: 19 APRIL 2017

ACKNOWLEDGEMENT

In the name of Allah, the Most Gracious and the Most Merciful. I am grateful to Him for providing the strength and means to complete this thesis. Praise be to Him Most High. My sincerest appreciation is extended to my supervisor Dr. Ammar Zakaria for his support, encouragement and guidance in completing this thesis. Besides that, I also want to thank KPM for the financial support. Many thanks go to my co-authors of my publications, Mr. Fathinul Syahir Ahmad Sa'ad and Prof. Ali Yeon Md Shakaff and all team members at Centre of Excellent for Advanced Sensor Technology (CEASTech) with who experiments were designed, data were collected and also for moral support rendered. I also would like to express my sincere thanks to my wife, kids and family for their kind support, patience and encouragement throughout these years. My deepest appreciation is also to all the School of Mechatronic Engineering members and UniMAP staffs for their help and kind hospitality.

TABLE OF CONTENTS

LIST OF FIGURES

NO **PAGE**

LIST OF TABLES

NO **PAGE**

LIST OF ABBREVIATIONS

CCD	Charge Couple Device
CFL	Compact Fluorescent
CMOS	Complementary Metal Oxide Semiconductor
DA	Discriminant Analysis
EIS	Electrical Impedance Spectroscopy
FD	Fourier Descriptor
fps	Frame per Second
GUI	Graphical User Interface
K-NN	k Nearest Neighbors
LED	Light Emitting Diode
NIR	Near Infra-Red
OS	Operating System
PCR	Principal Component Regression
PL	Programming Language
PLS	Partial Least Square
PTFE	Polytetrafluoroethylene
RAM	Random Access Memory
RFID	Radio Frequency Identification
RGB	Red, Green, Blue
RMS	Root Mean Square
SSC	Soluble Solid Content
TA	Titratable acidity
TSS	Total Soluble Solid
Δx	Difference in x-axis
Δy	Difference in y-axis
Δz	Difference in z-axis

Sistem Pelbagai-Sensor bagi Pengelasan Mangga Harumanis Berdasarkan Kualiti Luaran dan Dalamannya

ABSTRAK

Tesis ini membentangkan sistem pelbagai sensor untuk mengklasifikasikan mangga Harumanis berdasarkan kualiti luaran dan dalamannya. Kedua-dua kualiti luaran dan dalaman mangga Harumanis memberi kesan kepada pilihan pengguna. Kaedah semasa dalam mengklasifikasikan mangga Harumanis dilakukan secara manual dan merosakkan buah bagi menentukan kualiti dalamannya. Sistem yang dicadangkan terdiri daripada dua bahagian. Bahagian pertama adalah pengelasan berdasarkan kualiti luaran menggunakan sistem penglihatan mesin mengikut bentuk dan jisim. Bahagian kedua adalah pengelasan kualiti dalaman menggunakan near-infrared (NIR) spektroskopi, berdasarkan jumlah keseluruhan pepejal terlarut (TSS). Platform perolehan imej dibina untuk menangkap imej 3-Dimensi mangga Harumanis dalam satu proses tangkapan imej. Satu teknik pengukuran masa nyata telah dibangunkan dalam kajian ini. Kombinasi parameter penghurai Fourier dan parameter saiz-bentuk telah digunakan untuk mengenal pasti bentuk mangga Harumanis. Satu kaedah cakera dua dimensi yang lebih baik telah digunakan untuk menganggarkan isipadu mangga Harumanis berdasarkan imej yang diperoleh itu. Kemudian korelasi antara isipadu sebenar dan jisim sebenar telah diperolehi dan digunakan untuk menganggar jisim mangga Harumanis pada sistem 'in-line'. Kaedah yang dicadangkan boleh mengklasifikasikan mangga Harumanis mengikut bentuk dan jisim dengan ketepan 94.2% pada setiap masa. NIR spektrometer telah digunakan untuk mendapatkan panjang gelombang pantulan mangga Harumanis. Jus dari mangga itu telah diperoleh dan diukur dengan refractrometer untuk mendapatkan nilai TSS sebenar. Kemudian, panjang gelombang NIR yang diperolehi dianalisis dan dikaitkan dengan nilai TSS sebenar menggunakan analisis multivariat. Nilai regresi 0.85 untuk set penentukuran didapati daripada analisis, yang menjelaskan bahawa terdapat korelasi yang tinggi di antara panjang gelombang dan TSS. Kaedah analisis pembezalayan Stepwise digunakan untuk mencari panjang gelombang yang penting yang boleh digunakan untuk menentukan peringkat kematangan dalam sistem masa nyata. Sepuluh mata panjang gelombang telah dipilih dan disahkan pada set ujian. Model diskriminan boleh menentukan peringkat matang dengan ketepatan 85.0%.

Multi Sensor System for Classifying Harumanis Mango Based on External and Internal Quality

ABSTRACT

This thesis presents a multi sensor system for classifying Harumanis mango based on its external and internal quality. Both external and internal quality of Harumanis mango affects the consumer buying preferences. Current method of classifying Harumanis mango is done manually and destructive for its internal quality determination. The proposed system consists of two parts. First part is the external quality classification using machine vision system which is based on its shape and mass. The second part is the internal quality classification using near infrared (NIR) spectroscopy, based on its total soluble solid (TSS) value. An image acquisition platform was built to capture the 3-Dimensional image of Harumanis mango in a single acquisition. A real-time measurement calibration technique was developed in this research. Combination of Fourier descriptor parameters and size-shape parameters was used to recognize the shape of Harumanis mango. An improved two-dimensional disk method was used to estimate the volume of Harumanis mango based on the captures image. Then a correlation between the actual volume and actual mass was derived and used to estimate the mass of Harumanis mango on inline system. The proposed method can correctly classify the Harumanis mango according to its shape and mass 94.2% of the time. NIR spectrometer was used to obtain the reflectance wavelength of the Harumanis mango. The juice from the mango was obtained and measured with a refractrometer to obtain the actual TSS value. Then, the acquired NIR wavelength was analysed and correlate with the actual TSS value using multivariate analysis. A regression value of 0.85 for calibration set was found from the analysis, which explained that there was a high correlation between the wavelength and TSS. Stepwise Discriminant analysis method was used to find the significant wavelength that can be used to determine the maturity stage in real-time system. Ten wavelength points were selected and verified on the testing set. The discriminant model can be accurately determined the maturity stage with 85.0% accuracy.

CHAPTER 1

INTRODUCTION

1.1 Introduction to Harumanis Mango

Mango is one of the profitable agricultural products that export throughout the world, most notably from Asian countries such as India, Indonesia, Thailand, and Malaysia (Sa'ad et al., 2012). *Mangifera indica* L is the scientific name for mango, which has the same family with cashew and pistacia, which belong to the Anacardiaceae. The name of Mango which is called 'mangga' locally has been taken from the Tamil's word for mango which is mangas.

Mango is mostly famous fruit tree in the tropical and subtropical region, especially in the South-Eastern Asia. The cultivation of the mango has started for more than 4000 years and has been spread to many countries during that time (Norlia Ynus, 1984). Since that time, it has become one of the world's finest fruit in the history.

Harumanis mango is labelled as the *"King of Mangoes"* in Malaysia for its soft texture, sweetness and aromatic smell and perfect choice for the export market (Sa'ad et al., 2012). Market demand of the Harumanis mango is increasing every year, especially from the Japanese market. Despite the increasing demand, the Harumanis mango supply is far from enough to meet the market demand. Harumanis mango is categorized as one of the seasonal fruit and it can only be planted and grown in Perlis. Harumanis mango tree can only bear fruit once a year and the reproduction cycle start from January until the end of June (Zakaria et al., 2012). Thus, to eliminate the restraint in supply, Perlis State Government has agreed to allocate a significant amount of money for the Harumanis

mango sector. Under the Tenth Malaysia Plan, almost RM 9 million has been approved for the plantation of Harumanis mango tree with RM 1.8 million a year to the Department of Agriculture (Sa'ad et al., 2012). One thousand hectares of Harumanis mango new planting is targeted to be planted by 2015, which allocating 200 hectares for every year (Farook et al., 2011). Harumanis mango is different from any other mango as it is a temperamental fruit. It needs a long-dry season with minimum temperature of 40° Celsius. In Malaysia, only Perlis region had the dry season with 4-month long which made it the only place that can grow Harumanis mango (Saad et al., 2011). Rain, even drizzles can affect the yield output during this season. The mango needs to be wrapped with waterproof paper after the fruit is set. The fruit will be manually harvested by the workers after eight weeks. Next, it will be washed to remove any residues in the skin and then treated for five minutes in hot water to eradicate fruit fly and seed weevil larvae. The process ended with curing the mango in ripening chamber for three days. Figure 1.1 shows the Harumanis orchard at the Jabatan Pertanian Perlis.

Harumanis mango is a sweet-smelling fruit which has the mellow pulp texture. It has been known globally as one of the delicious mangoes. It does not change colour even it its maturity stage. While flesh is ripening, the skin colour remains green on the outside (Zakaria et al., 2012). Figure 1.2 shows the Harumanis mangoes that been harvested from the orchard in which are nearing its maturity stage. Perlis government is expecting to raise its yearly production, which presently allocated 350 tonnes for local markets (Farook et al., 2011). Even with the huge investment for Harumanis mango plantation, the greatest obstacle is to persuade the local farmers to practice the right agricultural technique. Perlis has exported 3.1 metric tons of Harumanis mangoes to Japan in 2012 and expecting to increase the export amount up to 100 metric tons by 2020 (Farook et al., 2011).

Figure 1.1: Harumanis mango tree at Jabatan Pertanian Perlis's orchard

Figure 1.2: Harumanis mango pick from the orchard

1.2 Problem Statements

Automated grading system still not been widely used in agro-based sector, especially in Malaysia. Current grading process at Jabatan Pertanian Perlis is done manually by experience workers only. Manual sorting and grading is time consuming, inefficient and labour intensive (Satpute & MJagdale, 2016). Purpose of automating the grading process is to increase its effectiveness and accuracy as well as reducing the processing time and labour cost (Patel, Kar, Jha, & Khan, 2012).

Machine vision can be very helpful for assisting human in the classifying and grading process (M. Omid, Khojastehnazhand, & Tabatabaeefar, 2010). Many researches have been done to determine the quality of the product, but most of them did not apply directly for the automated system (M. Omid et al., 2010; Spreer & Müller, 2011; Xiaobo, Jiewen, Yanxiao, Jiyong, & Xiaoping, 2008; Zakaria et al., 2012). Mango grading which based only on weight does not represent its overall qualities. Internal characteristic of the Harumanis mango also contribute to the quality attribute (Alfatni, Shariff, Abdullah, Marhaban, & Saaed, 2013; Sa'ad et al., 2012; Zakaria et al., 2012). Harumanis mango is famous for its sweetness. A quality measurement system is needed to determine the sugar level of the mango. Sugar level in a substance is referred as the total soluble solid (TSS) and measure in brix unit. TSS concentration always been measured by a refractometry method, which some juice are extracted from the sample and tested (Nagle, Mahayothee, Rungpichayapichet, Janjai, & Müller, 2010a; Valero & Ruiz-Altisent, 2000; Zakaria et al., 2012) . This method is destructive and not suitable to be used for sugar determination during post-harvest stage (Bobelyn et al., 2010; Subedi & Walsh, 2011). Thus, a non-destructive method is needed to determine mango sweetness intact. Before a non-destructive method can be carried out on the real site, a destructive test still need to be done to find the correlation between both methods.

1.3 Objectives

The main objective of this thesis is to develop a system using machine vision and NIR spectrometer for classifying Harumanis mango based on its shape, mass and TSS. The objectives of this research are divided and addressed as below:

1. To develop 3-Dimensional image acquisition technique for capturing image of the mango on a moving conveyor.
2. To analyse the Harumanis mango features and classify the mango based on the shape and mass.
3. To analyse the total soluble solid (TSS) of the mango using Near Infrared (NIR) spectrometer.

1.4 Significant of Studies

This research has a significant value especially in classifying the Harumanis mango. Harumanis mango which is known as seasonal fruit now is on the verge to be produced throughout the year. It will be mass produced and an accurate sorting system is needed. To ensure the best eating quality from it, the internal and external measurement must be done. The sweetness level of the mango will be the key to the customer's satisfaction. Furthermore, outcome of this system will use non-destructive method in carry out the quality assessment. Accurate outcome can be obtained without damaging the fruit. Further work on internal inspection can be done to determine another internal aspect such as firmness, maturity and water content.

1.5 Research Scope

Harumanis mango will be inspected for its internal and external quality. The scopes for this project are:

1. In-line process of classifying and grading the mango on the conveyor.
2. Classification and grading process is done at indoor environment.

1.6 Contributions of this Thesis

The main contributions of works in this thesis are:

1. In-line 3-dimensional measurement and calibration for mango.
2. Analysis of two dimensional disk method for volume determination.
3. Several classifier method for classifying the fruit shape.
4. Analysis of NIR reflectance for TSS measurement.

1.7 Thesis Outline

The general outline of this thesis is summarised below.

Chapter 2 provides a summary of visible imaging and NIR spectrometer in general fields and agriculture applications. Analysis regarding to shape, volume, mass and total soluble solid (TSS) are also discussed in the chapter. The base individual classifier also presented.

Chapter 3 describes image acquisition technique, data collection and analysis for the shape and mass of the Harumanis mango. The experimental setup and data collection to study the total soluble solid analysis using NIR spectrometer also explained.

Chapter 4 explains about the analysis of the shape and mass of Haruamnis mango. The individual classifier use for classifying shape and mass which is DA and K-NN is also discussed, followed by the partial least square (PLS) and principal component regression (PCR) to determine the brix value.

Finally, Chapter 5 summarises the research finding and contribution to the knowledge. Some future works that can extend this research are proposed at the end of the chapter.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Mango (*Mangifera indica* L.) is grouped amongst the famous tropical fruits and has been planted in more than 80 countries throughout the world (Bally, 2011). The crop produced was calculated to be more than 38.9 million of tons per year and ranked fifth in total production of fruit yields worldwide (Del Claro, S. Oliveira, & Rico-Gray, 2009). Mango quality is affected by the stage of maturity, among other factors. During the maturity stage, the occurrence of biochemical, physiological and molecular changes affecting its quality traits directly (Ibarra-Garza, Ramos-Parra, Hernández-Brenes, & Jacobo-Velázquez, 2015). The ability to determine the exact time for harvesting has becomes one of the most important factors in agriculture sector. Conventional method that been used to determine fruit maturity is based on the scent, skin texture, skin colour and harvesting time (Khoje & Bodhe, 2013). In some cases, fruits were harvested earlier than expected for exported market, but the early maturity of fruit has led to quality deterioration due to fruit disorders. An indication technique which will be able to identify and utilise the volatiles emitted or internal characteristics of the different maturity stages could help to solve this problem. In recent years, a numerous studies has been conducted to determine the type of volatile compound produce during the ripening period such as α-pinene, γ-terpinene and terpinolene (Hawari et al., 2013).

High-quality food production is also depends on the decent choice of raw fruit rather than rely solely on the processing technologies. The current research on the post-

harvest maturity period of mango highlight the crucial aspects to achieve better quality of mango products and to encourage the practice of consuming mango with improved health benefits (Ibarra-Garza et al., 2015). In this chapter, researches which are related to the determination of external and internal quality of agricultural product will be explained.

2.2 External Quality Inspection of Agriculture Product

There are two types of quality inspection that usually been used for grading agricultural products. First is the agricultural grading systems based on the external quality which had been studied recently by (Alfatni et al., 2013). The second type, which has gained interest from many researches in the recent years, is to grade the agricultural product based on its internal quality. Old-fashioned methods have been deployed for a long time but they are costly, tedious and time consuming. Several previous system that been used are also believed to suffer harshly from individual interpretations leading to discrepancies. Even when the system is considered as impartial, it is unsuccessful to sustain the huge-scale production needs in the present time. Nonetheless, this technology is the right technique to perform external inspection because of the restricted depth that can be penetrated by the inspecting source. In the past few years, the world has seen many advanced invention for solving the problem of automating the internal grading. External condition has been the most important sensory evaluation for quality trait of vegetables and fruits. Consumer's preference and choice, products market values as well as the internal quality are affected by the external quality. The quality assessment process for vegetables and fruits based on their external condition is normally done on their colour, size, texture, shape, as well as the surface flaws. The process is consuming much time and much labour work needed in grading the vegetables and fruits for its external quality

manually. Food processing industries have been extensively applying the concept of machine vision system for their quality assessment. The system which included the hyperspectral machine vision systems, multispectral machine vision system and also the traditional machine vision system, has been an influential components for precise and accurate external quality assessment for agricultural and foods products (Alfatni et al., 2013).

For agricultural products, external quality has been the most significant sensory evaluation by the consumers. Costa et al. (2009) described that shape, size, colour, texture and visual flaws are the important parameters in considering the external quality of vegetables and fruits (Costa et al., 2009). The sale value and buyer's purchasing behaviour for vegetables and fruits are affected by the external appearance. In some cases, the defective, infested and contaminated vegetables and fruits can cause the infection or contagion to spread among the healthy products. In the event of worse cases, the entire batch can be affected which can cause excessive economic losses as well as the safety issues (ElMasry, Wang, Vigneault, Qiao, & ElSayed, 2008). Thus, it is very important during the post-harvest stage to undergo the external quality inspection (Teena, Manickavasagan, Mothershaw, El Hadi, & Jayas, 2013).

Automating the external quality assessment of vegetables and fruits is a challenging task. Several automated system had been implemented for grading base on external quality measures such as shape, colour, texture and size by the industrial graders. But to grade vegetables and fruits based on the other appearance aspects, such as rottenness, bruise and few other unclear flaws that have the same texture and colour like the healthy peel, or flaws that been continuously misjudges with the calyxes and stem-end, is not yet effective. Therefore, manual operation is still the favourite choice for grading process (Leemans & Destain, 2004). There are few disadvantages for manual

grading such as discrepancy, timewasting, subjectivity and variability. Furthermore, the manual procedure is also laborious, costly, tedious and easily affected by the working atmosphere (Razmjooy, Mousavi, & Soleymani, 2012). Therefore, the development of an automated system has been an urgent and essential need for external quality inspection to substitute the manual inspection. Almost all of the external quality features are inspected visually, thus machine vision offers a great advantages to automate this task (Aleixos, Blasco, Navarrón, & Moltó, 2002). Patel, Kar, Jha, & Khan (2012) described computer vision as an association of the optical instrumentation, electromagnetic sensing, mechanics, digital video and image processing tools which includes in the engineering technology (Patel et al., 2012). The science is accountable for the research founding. Gómez-Sanchis et al. (2012) described the techniques which give an ability to the computer to recognise the contents of an image, which also included the extraction of several features that vital for a specified goal (Gómez-Sanchis et al., 2012). The establishment of computer vision as an equipment for safety and quality assessment of a variety of food and agricultural products was started since the past decade. Brosnan and Sun (2002) stated that the purpose of the automatic external quality grading is to mimic the ability of human vision by understanding and perceiving an image electronically, and explain the external characteristics of vegetables and fruits thus provide the information to the grading machine to sort the product base on its external quality (Brosnan & Sun, 2002).

Traditional grading system with the conventional RGB colour video cameras is the commonly used computer vision system for quality inspection which can mimic the ability of a human eyes by using three sensors centred at red (R), green (G) and blue (B) wavelengths to acquire image (Lorente et al., 2012). Traditional computer vision system can be used to estimate or identify the characteristics that can be detected externally such