



**HIGH-LEVEL DATA FUSION FOR ‘*INSIDIOUS  
FRUIT ROT*’ (IFR) DETECTION OF *HARUMANIS  
CULTIVAR***

by

**Nurul Syahirah Binti Khalid  
1640612295**

A thesis submitted in fulfillment of the requirements for the degree of  
Doctor of Philosophy

**Faculty of Electrical Engineering Technology  
UNIVERSITI MALAYSIA PERLIS**

2020

## ACKNOWLEDGMENT

My utmost gratitude goes to the Creator Ya Wakil Ya Hakim Ya Wahhab - for all the experiences, lessons and gifts in completing my PhD journey. Million thanks and deepest appreciation to my beloved main supervisor, Associate Professor Dr. Shazmin Aniza binti Abdul Shukor, who have provided me with endless support, guidance, fruitful discussion advice throughout my study. Her mentorship, skills, expertise, dedication, passion and curiosity for researches have inspired me. Many thanks to my co-supervisor, Dr. Fathinul Syahir bin Ahmad Sa'ad for the support during my journey. I would also appreciate to Associate Professor. Ir. Dr. Abu Hassan Abdullah for his first insight and guidance throughout the early days which has helped me to build the foundation in my research work.

My sincere thanks to Postgraduate Society of the School of Mechatronic Engineering, for the discussion on statistical analysis and machine learning, which has helped me to bring the thesis to full completion. My deepest appreciation also to Dr. Maz Jamilah binti Masnan for consistent, valuable guidance and help throughout this study. This study would not have been possible without the financial support and opportunity from the Ministry of Education Malaysia as well as UniMAP.

Special thanks to the Department of Standards Malaysia and Federal Agricultural Marketing Authority (FAMA) Selayang and Perlis for supplying the batches of *Harumanis cv.* samples especially to Encik Rahim, Encik Mazalan, Encik Khairi, Encik Shukri and all other FAMA staff for helping me either direct or indirectly. Thanks to Puan Daleyla and Encik Hafiz from Malaysia Agriculture Research and Development Institute (MARDI) Sintok, Kedah for the knowledge about disorder in *Harumanis cv.*

I am forever indebted to my beloved parents, Khalid bin Ahmad Zahari and Jamaliah bt. Md. Basir for their continuous encouragement and du'a. My humble thanks to all my family members for the endless moral support. Finally, my deepest appreciation and thanks to my beloved husband Ismail Ishaq Ibrahim for his sacrifices, understanding, motivation, du'a and never-ending loves. I hope that this tiny masterpiece would instigate more significance researches for the goodness of mankind. May Allah accept this work as good-deed.

## TABLE OF CONTENTS

	<b>PAGE</b>
<b>DECLARATION OF THESIS</b>	<b>i</b>
<b>TABLE OF CONTENTS</b>	<b>iii</b>
<b>LIST OF TABLES</b>	<b>vii</b>
<b>LIST OF FIGURES</b>	<b>x</b>
<b>LIST OF ABBREVIATIONS</b>	<b>xv</b>
<b>LIST OF SYMBOLS</b>	<b>xvii</b>
<b>ABSTRAK</b>	<b>xviii</b>
<b>ABSTRACT</b>	<b>xix</b>
<b>CHAPTER 1 : INTRODUCTION</b>	<b>1</b>
1.1 Research Background	1
1.2 Problem Statement and Motivation	6
1.3 Aim and Objectives	7
1.4 Research Scope	8
1.5 Research Contributions	11
1.6 Thesis Outline	12
<b>CHAPTER 2 : LITERATURE REVIEW</b>	<b>14</b>
2.1 Introduction	14
2.2 Mango Production and Post-harvest Issues	14
2.2.1 Mango Quality Attributes and Sensory Properties	18
2.2.2 ' <i>Insidious Fruit Rot</i> ' (IFR) in <i>Harumanis cv.</i>	21
2.3 Problems in Deciding Suitable Techniques for Fruits Quality Evaluation	23

2.4	Non-destructive Sensor in Fruits Sensory	25
2.4.1	Image Processing Technique in Agricultural Product	28
2.4.1.1	Specific Gravity as a Quality Indicator	29
2.4.2	Near-Infrared (NIR) Spectroscopy Application for Agricultural Product	32
2.4.2.1	Application of NIR Spectroscopy for Internal Conditions Measurement of Agricultural Product	34
2.4.3	Electronic noses (E-nose) Applications in Food Sensory	39
2.4.3.1	Mango Volatile Compounds	41
2.5	The Need for Multi-Sensor Data Fusion	45
2.6	Framework of Sensor Fusion	49
2.6.1	Discussion on LLDF, MLDF and HLDF	55
2.6.2	HLDF as Classification Method	57
2.6.2.1	Dempster-Shafer (D-S) Inference Techniques	61
2.6.2.2	Majority Voting (MVT)	62
2.7	Summary	63
<b>CHAPTER 3 : METHODOLOGY</b>		<b>65</b>
3.1	Introduction	65
3.2	Sample Preparation	68
3.3	Specific Gravity Measurement by Using Archimedes' Theory	69
3.4	<i>IFR</i> Prediction by Using Image Processing Technique	71
3.4.1	Element of Machine Vision and Experimental System Setup	74
3.4.2	Specific Gravity Measurement	75
3.4.2.1	Proposed Method by using Image Processing Techniques	76
3.5	<i>IFR</i> Prediction by using NIR Spectroscopy	81
3.5.1	Element of NIR Spectroscopy and Experimental System Setup	84

3.5.2	Raw Spectral Selection and <i>Hotelling T2</i> Ellipse to Detect Spectra Outliers	87
3.5.3	Pre-treatment, Calibration and Model Predictive of Specific Gravity	89
3.6	<i>IFR</i> Prediction by using E-nose	92
3.6.1	Element of E-nose and Experimental System Setup	94
3.6.2	Normality Test and Baseline Manipulation	96
3.7	Single-Sensor Classification Analysis Method	99
3.7.1	Support Vector Machine (SVM)	99
3.7.2	K-Nearest Neighbour (KNN)	100
3.8	Fusion Data from Image Processing Technique, NIR Spectroscopy and E-nose	102
3.8.1	High-Level Data Fusion (HLDF) Method	103
3.8.1.1	Dempster-Shafer (D-S) Method	104
3.8.1.2	Majority-Voting (MVT) Method	106
3.9	Summary	107
<b>CHAPTER 4 : RESULTS AND DISCUSSIONS</b>		<b>108</b>
4.1	Introduction	108
4.2	Specific Gravity Measurement Results from Archimedes' Theory	111
4.3	<i>IFR</i> Existence Detection by Using Image Processing Technique	112
4.3.1	Specific Gravity and <i>IFR</i> Prediction by Using Image Processing Technique	113
4.3.2	Raw Data Validation by MANOVA for Predicted Specific Gravity by using Image Processing Technique	114
4.3.3	Classification by Using Base Classifier of SVM and KNN for Specific Gravity by Using Image Processing Technique	115
4.4	<i>IFR</i> Existence Detection in <i>Harumanis cv.</i> Using NIR Spectroscopy	117
4.4.1	NIR Spectroscopy Mean-Spectra of Raw Data NIR Spectroscopy	118
4.4.2	<i>Hotelling T2</i> Ellipse to Detect Spectra Outliers	119

4.4.3	Calibration Model Selection	121
4.4.4	Data Pre-processing and PLS Analysis	122
4.4.5	Raw Data Validation by MANOVA for Predicted Specific Gravity by using NIR Spectroscopy	125
4.4.6	Classification by Using Base Classifier of SVM and KNN for Specific Gravity by Using NIR Spectroscopy	125
4.5	<i>IFR</i> Existence Detection in <i>Harumanis cv.</i> by Using Aroma from E-nose	128
4.5.1	Normality Test and Baseline Manipulation	128
4.5.2	Feature Extraction by using PCA	132
4.5.3	Raw Data Validation by MANOVA for Aroma by using E-nose	133
4.5.4	Classification by Using Base Classifier of SVM and KNN for Aroma by Using E-nose	134
4.6	Data Fusion Implementation and Analysis	137
4.6.1	D-S Fusion Method	137
4.6.2	Majority Voting (MVT) Method	143
4.7	Discussion of Comparison Classification Result of Single-Sensor and Multi-Sensor Method	148
4.8	Summary	152
	<b>CHAPTER 5 : CONCLUSION AND FUTURE WORK</b>	<b>154</b>
5.1	Summary of Study	154
5.2	Recommendations for Future Work	157
	<b>REFERENCES</b>	<b>159</b>
	<b>LIST OF PUBLICATIONS</b>	<b>176</b>

## LIST OF TABLES

		PAGE
Table 1.1	The target and actual export of <i>Harumanis cv.</i> mango to Japan (Farook et al., 2011)	4
Table 2.1	General quality components of fresh fruit (Kader, 2002)	19
Table 2.2	Non-destructive methods to evaluate the quality characteristics of mango (Aboonajmi & Faridi, 2016)	27
Table 2.3	Agriculture product related with their internal quality assessment, features and types of sensor used	38
Table 2.4	List of sensors used to develop the E-nose system for classification of beverages (Mango, orange and blackcurrant)	41
Table 2.5	List some of climacteric and non-climacteric fruits and vegetables	43
Table 2.6	Application of HLDF in agricultural applications	59
Table 3.1	Characteristics of <i>Harumanis cv.</i> samples used in this research	68
Table 3.2	The form of data for a PCA with $p$ features on $n$ cases	89
Table 3.3	List of sensors used	95
Table 4.1	MANOVA test for specific gravity raw data by using image processing technique	114
Table 4.2	Confusion matrix SVM based classifier for specific gravity from image processing technique for detecting the existence of <i>IFR</i> in <i>Harumanis cv.</i>	116

Table 4.3	Confusion matrix KNN based classifier for specific gravity from image processing technique <i>IFR</i> in <i>Harumanis cv.</i> detection	116
Table 4.4	Statistical parameters and results of the PLS and PCR model for specific gravity for the 400 nm to 1000 nm wavelength range	121
Table 4.5	Statistical parameters and results of the PLS and PCR model for specific gravity prediction for the 400 nm to 1000 nm wavelength range	122
Table 4.6	Data treatment results of the PLS model for specific gravity prediction for the NIR wavelength range 400 nm to 699 nm	124
Table 4.7	MANOVA test raw data by using NIR spectroscopy	125
Table 4.8	Confusion matrix SVM based classifier for specific gravity from NIR spectroscopy for detecting the existence of <i>IFR</i> in <i>Harumanis cv.</i>	126
Table 4.9	Confusion matrix KNN based classifier for specific gravity from NIR spectroscopy for detecting the existence of <i>IFR</i> in <i>Harumanis cv.</i>	127
Table 4.10	Summary of normality test for all E-nose dataset	130
Table 4.11	MANOVA test for aroma raw data by using E-nose	134
Table 4.12	Confusion matrix SVM based classifier aroma dataset for detecting the existence of <i>IFR</i> in <i>Harumanis cv.</i>	135
Table 4.13	Confusion matrix KNN based classifier aroma dataset for detecting the existence of <i>IFR</i> in <i>Harumanis cv.</i>	135
Table 4.14	Classification accuracy of SVM and D-S Fusion for specific gravity from image processing technique and specific gravity from NIR spectroscopy	139

Table 4.15	Classification accuracy of SVM and D-S Fusion for specific gravity from NIR spectroscopy and aroma from E-nose	139
Table 4.16	Classification accuracy of SVM and D-S fusion for aroma from E-nose and specific from image processing technique	140
Table 4.17	Classification accuracy of SVM and D-S fusion for specific gravity from image processing technique, specific gravity from NIR spectroscopy and aroma from E-nose	140
Table 4.18	Classification accuracy of SVM and MVT fusion for specific gravity from image processing technique and specific gravity from NIR spectroscopy	144
Table 4.19	Classification accuracy of SVM and MVT fusion for specific gravity from NIR spectroscopy and aroma from E-nose	144
Table 4.20	Classification accuracy of SVM and MVT fusion of aroma from E-nose and specific gravity from image processing technique	145
Table 4.21	Classification accuracy of SVM and MVT fusion for specific gravity from image processing technique, specific gravity from NIR Spectroscopy and aroma from E-nose	145

## LIST OF FIGURES

	<b>PAGE</b>
Figure 1.1 The spread of mango from India to another country (Harbinson & Kooten, 2005)	2
Figure 1.2 <i>Harumanis cv.</i> affected by <i>IFR</i>	5
Figure 1.3 Healthy <i>Harumanis cv.</i> sample	5
Figure 1.4 K-chart of mango quality attributes	9
Figure 1.5 K-chart of experimental techniques used in mango quality attributes	10
Figure 1.6 An integrated conceptual framework of this research on prediction existence of <i>IFR</i> in <i>Harumanis cv.</i> (selected properties); physical properties, aroma properties and mechanical properties.	11
Figure 2.1 Pre and post-harvest factors that can affect fruits quality (Harbinson & Kooten, 2005)	15
Figure 2.2 The manual sorting for mango that have been done in a local rural industry (Momin et al., 2017)	17
Figure 2.3 <i>Harumanis cv.</i> inspection that have been done by graders in Perlis area industry	17
Figure 2.4 Phenological stage for mango (Mango, 2019)	19
Figure 2.5 <i>Harumanis cv.</i> severely affected by <i>IFR</i> (Tarmizi et al., 1993)	22
Figure 2.6 Overview of non-destructive sensors selection in predict the existence of <i>IFR</i> in <i>Harumanis cv.</i>	28

Figure 2.7	Ideal projections of the major and minor axes	32
Figure 2.8	Interaction of organic material with NIR spectroscopy radiations on sample (Bhunase & Patil, 1998)	34
Figure 2.9	Illustration of E-nose that imitate human basic senses	40
Figure 2.10	Formation of volatiles aroma in fruits and vegetables (Salunkhe and Do, 1976)	42
Figure 2.11	Climacteric fruits phase	44
Figure 2.12	Human combined several senses for better decision making (Zhou, Zhang, Qiu, & He, 2020)	45
Figure 2.13	Overview graphical of data fusion in food application (Borràs et al., 2015)	47
Figure 2.14	Mathematical algorithms for data fusion (Klein, 2004)	48
Figure 2.15	Diagrams for the JDL data fusion frameworks (a) LLDF model (b) ILDF model, and (c) HLDF model (Masnan, 2017)	51
Figure 2.16	Proposed methodology of sensor fusion to fruit quality assesment (Steinmetz et al., 1999)	53
Figure 3.1	Overall research methodology flowchart for predict the existence of <i>IFR</i> in <i>Harumanis cv.</i>	67
Figure 3.2	<i>Harumanis cv.</i> sample in water filled beaker	70
Figure 3.3	Flowchart for single-sensor analysis of image processing	73
Figure 3.4	Basler CCD camera (BaslerWeb, 2019)	75
Figure 3.5	Main frame of the platform	75
Figure 3.6	Specific gravity flowchart calculation and <i>IFR</i> prediction for <i>Harumanis cv.</i> using image processing	77

Figure 3.7	Dimension of <i>Harumanis cv.</i> samples in cylindrical shape	80
Figure 3.8	Major and minor axis dimension applied on <i>Harumanis cv.</i>	81
Figure 3.9	Flowchart for single-sensor analysis of NIR spectroscopy	83
Figure 3.10	NIR spectroscopy equipment	85
Figure 3.11	Graphic diagram of the four scanned internodes (Nawi et al., 2013)	86
Figure 3.12	External reflection spectroscopy measurements (Cortés et al., 2016)	86
Figure 3.13	The position of the NIR spectroscopy probe located in the area of sinus region	87
Figure 3.14	Flowchart for single-sensor analysis of E-nose	93
Figure 3.15	Typical block diagram of human olfaction and E-nose	95
Figure 3.16	The E-nose setup for collecting data	95
Figure 3.17	Fusion of three sensors	102
Figure 3.18	High-level data fusion concept	104
Figure 4.1	<i>Harumanis cv.</i> sample affected by <i>IFR</i>	110
Figure 4.2	Relationship plot between volume and mass of the 500 <i>Harumanis cv.</i> samples	111
Figure 4.3	Specific gravity of the 500 <i>Harumanis cv.</i> against number of samples	112
Figure 4.4	Scatter plot of the specific gravity by using image processing technique (predicted specific gravity) againsts specific gravity by using Archimedes' Theory	113
Figure 4.5	SVM and KNN based classifier for training data performance	117

Figure 4.6	SVM and KNN based classifier for testing data performance	117
Figure 4.7	NIR raw mean spectra in wavelength range of 194.13 <i>nm</i> to 1041 <i>nm</i>	118
Figure 4.8	NIR raw mean spectra in wavelength range of 400 <i>nm</i> to 1000 <i>nm</i>	119
Figure 4.9	Plot of the first principal component (PC1) against the second principal component (PC2) for both <i>IFR</i> tissue and healthy tissue	120
Figure 4.10	Hotelling <i>T</i> <sup>2</sup> ellipse applied to the raw spectra of 500 samples after PCA for outlier detection	120
Figure 4.11	Scatter plot of PLS model for predicted specific gravity and specific gravity by using Archimedes' Theory of <i>Harumanis cv.</i>	124
Figure 4.12	SVM and KNN based classifier for training data performance	127
Figure 4.13	SVM and KNN based classifier for testing data performance	128
Figure 4.14	PCA plot of condition of <i>Harumanis cv.</i> samples	133
Figure 4.15	SVM and KNN based classifier for training data performance	136
Figure 4.16	SVM and KNN based classifier for testing data performance	136
Figure 4.17	Comparison of SVM and D-S Fusion for specific gravity from image processing technique and specific gravity from NIR spectroscopy	141
Figure 4.18	Comparison of SVM and D-S Fusion for specific gravity from NIR spectroscopy and aroma from E-nose	141
Figure 4.19	Comparison of SVM and D-S fusion for aroma from E-nose and specific gravity from image processing technique	142

Figure 4.20	Comparison of SVM and D-S fusion for specific gravity from image processing technique, specific gravity by from NIR spectroscopy and aroma from E-nose	142
Figure 4.21	Comparison of SVM and MVT fusion for specific gravity from image processing technique and specific gravity from NIR spectroscopy	146
Figure 4.22	Comparison of SVM and MVT fusion for specific gravity from NIR spectroscopy and aroma from E-nose	146
Figure 4.23	Comparison of SVM and MVT fusion of aroma from E-nose and specific gravity from image processing technique	147
Figure 4.24	Comparison of SVM and MVT fusion using of specific gravity from image processing technique, specific gravity from NIR spectroscopy and aroma from E-nose	147
Figure 4.25	Classification performance of single-sensor by using SVM and merged sensor (D-S fusion and MVT fusion)	151

## LIST OF ABBREVIATIONS

cv.	Cultivar
RM	Ringgit Malaysia
kg	Kilogram
<i>IFR</i>	Insidious Fruit Rot
FAMA	Department of Standards Malaysia and Federal Agricultural Marketing Authority
DOA	Department of Agriculture
MARDI	Malaysia Agriculture Research and Development Institute
NIR	Near-Infrared Spectroscopy
JDL	Joint Directors of Laboratories
FAO	Food and Agriculture Organization of the United Nations
NMR	Nuclear Magnetic Resonance
CT	Computerized Tomography
MRI	Magnetic Resonance Imaging
E-tongue	Electronic tongue
E-nose	Electronic nose
SEE	Standard Error of Estimation
2D	Two Dimension
3D	Three Dimension
DM	Dry Matter
SSC	Soluble Solid Content
VOC	Volatile Organic Compound
LAAS	Laboratoire d'Analyse et d'Architecture des Syst`emes
U.S.	United State
LLDF	Low-Level Data Fusion
ILDF	Intermediate/Mid- Level Data Fusion
HLDF	High-Level Data Fusion
VIS-NIR	Visible Spectroscopy
D-S	Dempster-Shafer
MVT	Majority Voting
HS	Healthy Sample
SG	Specific Gravity
PLS	Partial Least Square

PCR	Principal Component Regression
CCD	Charged Coupled Device
PVC	Polymerizing Vinyl Chloride
MANOVA	Multivariate Analysis of Variance
RGB	Red-Green-Blue
CSSM	Cross Sectional Scanning Method
SSM	Skin Scanning Method
SNV	Standard Normal Variate Transformation
MSC	Multiplicative Scatter Correction
S-G	Savitzky-Golay
SNR	Signal-to-Noise-Ratio
PCA	Principal Component Analysis
MLR	Multiple Linear Regression
LVs	Latent Variables
PC	Principal Component
RMSEC	Root Mean Square Error of Calibration
RMSECV	Root Mean Square Error for Cross Validation
RMSEP	Root Mean Square Error of Prediction
SVM	Support Vector Machine
KNN	K-Nearest Neighbour
RBF	Radial Basis Function
SS1	Single-sensor 1 (Image processing technique)
SS2	Single-sensor 2 (NIR spectroscopy)
SS3	Single-sensor 3(E-nose)
Min	Minimum
Max	Maximum
SG	Specific Gravity

## LIST OF SYMBOLS

$\%$	Percent
$m$	Mass
$V$	Volume
$\rho$	Density
$nm$	Nanometer
$mL$	Mililiter
$\pm$	Plus minus sign
$^{\circ}C$	Degree Celsius
$g$	Gram
$SG$	Specific Gravity
$\rho_{mango}$	Density Mango
$\rho_{water}$	Density Water
$T$	Threshold Value
$r$	Radius
$h$	Height
$V$	Volt
$W$	Watt
$mm$	Milimeter
$R$	Pearson
$R$	Reflectance
$K$	Kernel Function
$g/cm^3$	Gram per Cubic Centimeter
$V_{sm}$	Volume of Sample
$V_{am}$	Volume of Water after Sample is Submerged
$V_{bm}$	Volume of Water before Sample is Submerged
$\pi$	Pi
$R^2$	Multiple Correlation
$X_{bl}$	Baseline Manipulation Data
$X_m$	Sample Data
$X_o$	Reference Data

## Gabungan Data Tahap-Tinggi Bagi Mengesan “Pereputan Buah Dalam” (IFR) Bagi Kultivar Harumanis

### ABSTRAK

*Harumanis cv.* dikenali sebagai raja mangga di mana ianya dapat menghasilkan pengeluaran yang banyak setiap tahun tetapi kualitinya perlu dinilai sebelum dijual atau dieksport. Pendekatan sedia ada bagi menilai kualiti buah ini bergantung semata-mata pada pemerhatian manual berdasarkan pengalaman peribadi penilai, di mana hanya parameter luaran sahaja yang diambil kira dan ini boleh menghasilkan ralat disebabkan ketidakjitian oleh pemeriksa manusia. Tambahan pula, cara ini tidak dapat menilai kualiti ciri dalaman *Harumanis cv.* memandangkan *Harumanis cv.* cenderung diserang kecacatan fisiologi yang hanya boleh dikesan melalui pemusnahan. Salah satu kecacatan fisiologi utama adalah kerosakan dalaman yang dikenali sebagai “Pereputan Buah Dalam” (IFR) yang memberi kesan terhadap seluruh pengeluaran. Maka, kaedah tidak musnah dalam penggredan buah dengan mengambil kira kewujudan IFR adalah perlu. Kamera *Charged Coupled Device* (CCD), Spektroskopi Infra-Merah Jarak Dekat (NIR) dan Hidung elektronik (E-hidung) adalah teknik analitikal yang digunakan secara berasingan dalam memeriksa kualiti makanan bagi memeriksa graviti khusus dan bau. Dalam kerja ini, gabungan ketiga-tiga jenis penderia ini akan digunakan untuk meningkatkan kepercayaan dalam mengklasifikasikan keadaan *Harumanis cv.* jika dibandingkan dengan bergantung hanya pada sesuatu teknik penderia. Untuk mendapatkan ketepatan penilaian yang tinggi, himpunan data aras-tinggi dicadangkan bagi menggabungkan pelbagai perwakilan menjadi satu dengan menggunakan teknik gabungan *Dempster-Shafer* (D-S) dan *Majority Voting* (MVT). Dua jenis klasifikasi dasar; *Support Vector Machine* (SVM) dan *K-Nearest Neighbours* (KNN) digunakan untuk menganalisa prestasi sesuatu penderia. Eksperimen dijalankan untuk mengesahkan pendekatan yang dicadangkan. Empat peringkat ujian termasuk; pertama, gabungan graviti khusus daripada pemprosesan imej dan spektroskopi NIR; seterusnya, gabungan graviti khusus daripada spektroskopi NIR dan bau daripada E-hidung; ketiga, gabungan aroma daripada E-hidung dan graviti khusus daripada pemprosesan imej; dan akhirnya, gabungan graviti khusus dengan daripada pemprosesan imej, graviti khusus daripada spektroskopi NIR dan bau daripada E-hidung. Keputusan eksperimen menunjukkan prestasi klasifikasi teknik yang dicadangkan memberi prestasi yang lebih baik dibandingkan dengan satu penderia secara am, di mana teknik gabungan yang terbaik adalah D-S bagi graviti khusus daripada pemprosesan imej dan graviti khusus daripada spektroskopi NIR dengan ketepatan 96.87%. Sementara itu, teknik terbaik untuk gabungan kesemua penderia solo menggunakan gabungan D-S (95.80% ketepatan) dibandingkan teknik MVT (87.92% ketepatan). Ini membuktikan IFR boleh dikesan secara teknik tidak musnah dengan menggabungkan penderia yang sesuai dan teknik ini diharap dapat memberi faedah dalam membantu petani dan pakar pertanian dalam penggredan dan penilaian dalaman *Harumanis cv.* pada masa hadapan.

## High-Level Data Fusion for ‘Insidious Fruit Rot’(IFR) Detection of Harumanis cv.

### ABSTRACT

*Harumanis cv.* is known as the king of mangoes where every year, large amount of this mangoes is produced and its quality assessments need to be evaluated before being sold or exported. Existing approach to evaluate the quality of the fruit is solely depending on manual observation based on personal experiences, where only external parameters are considered and this could lead to some errors due to inconsistencies made by human inspection. Furthermore, this approach has problems in evaluating the internal characteristics quality of *Harumanis cv.*, as *Harumanis cv.* are prone to physiological disorder that can only be detected destructively. One of the mainly physiological disorder attack is the internal breakdown known as ‘*Insidious Fruit Rot*’ (*IFR*) which has affected the overall production of the fruit. Therefore, there is a need to have a non-destructive method in grading the fruit according to its internal quality based on the presence of *IFR*. Charged Coupled Device (CCD) camera, Near-Infrared (NIR) Spectroscopy and Electronic nose (E-nose) are the analytical techniques which have been used separately in the food quality appraisal to measure specific gravity and aroma of fruits. In this work, fusion of these three sensors will be used as a mean to increase the reliability of classification of *Harumanis cv.* condition internally as compared to depending only to a single analytical technique. To get higher accuracy for quality appraisal, high-level data fusion is proposed to fuse these multiple representations using Dempster-Shafer (D-S) and Majority Voting (MVT) fusion techniques. Two types of based classifier; Support Vector Machine (SVM) and K-Nearest Neighbours (KNN) were used to analyze the performance of the single-sensor used. Experimental procedures are then performed to validate the proposed approach. Four testing stages were included; firstly, specific gravity fusion from image processing and NIR spectroscopy; next, specific gravity and aroma fusion from NIR spectroscopy and E-nose; thirdly, fusion of aroma from E-nose and specific gravity from image processing; and lastly, fusion of specific gravity from image processing and NIR spectroscopy with aroma from E-nose. The experimental results show that the proposed method has better performance classification compared with using single-sensor technique in general, where the best fusion method is by applying D-S for specific gravity from image processing technique and specific gravity from NIR spectroscopy with 96.87% accuracy for overall cases. Meanwhile, the best technique in fusing all single-sensors is by applying D-S fusion (95.80% accuracy) compared to MVT method (87.92% accuracy). This proves that *IFR* can be detected non-destructively by fusing related techniques and this method is hope to be beneficial in helping farmers and agricultural experts in grading and evaluating *Harumanis cv.* internally in the future.

## CHAPTER 1 : INTRODUCTION

### 1.1 Research Background

Mango is categorized as one of the most ancient cultivated fruits crops and world's most popular tropical fruits with a rising production trend every year (Ganiron, 2014). Mango or its scientific name *Mangifera indica L.* belongs to dicotyledonous family members of *Anacardiaceae* and taxonomically belongs to the genus *Mangifera*. This tropical fruit has its origin from Indo-Burma region and has been cultivated in India more than 4000 years (State, 2016). Beginning in the 16<sup>th</sup> century, mangoes were disseminated from India to other tropical countries in Asia such as the Philippines, Indonesia, China and Thailand by sailors, traders and missionaries. In 1993, Galan (1993) reported that the production of mango worldwide has increased by approximately 50 percent between 1971 and 1993.

Mango has been an enjoyable aromatic and flavour fruit, with exclusive taste and contains rich vitamin A compared to other fruits (Nip, 1991). It is mostly eaten up raw as a dessert fruit and small bulk are also prepared into mango juice, jellies, jams, nectars and preserves. There are more than a thousand varieties of mango under cultivation but only a small number of cultivar (*cv.*) are grown on a commercial scale. For the time being, mango is an important commercial crop not only in India, but also in Indonesia, Thailand as well as in Malaysia. According to Vasanthaiah, Ravishankar, & Mukunda (2007), the highest concentration of mango species is reported in Malayan Peninsular, followed by the Sunda Islands and the Eastern Peninsula with many of the genus being common

between of them. Figure 1.1 presents the spread of mango from the original region cultivation to Malaysia and around the world.

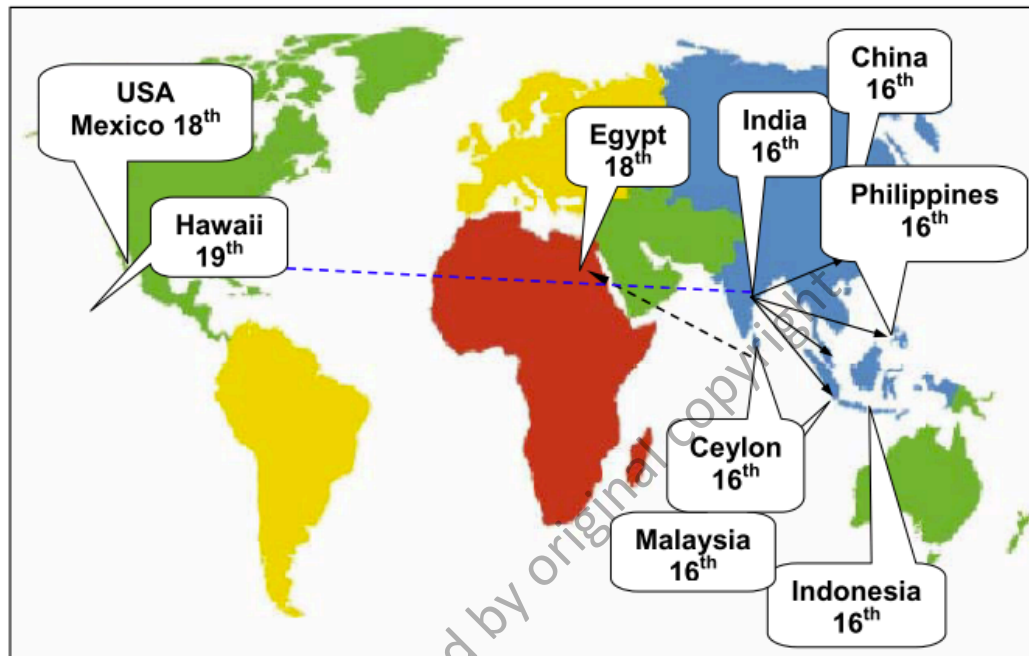


Figure 1.1 The spread of mango from India to another country (Harbinson & Kooten, 2005)

In Peninsular Malaysia, mango is grown in a limited, mixed property or orchard. According to “Malaysia Fruit Crops Statistics” report produced by Department of Agriculture (DOA) Putrajaya, Malaysia in 2017, the area of mango orchard in Peninsular Malaysia is 6048.29 hectare. Today, there are over 300 mango cultivars with considerably in different size, shape, colour, flavour and fibre contents in Malaysia. A good mango is juicy, sweet and may also have its own attractiveness and variation.

One of the well-known mango cultivar that has its own unique characteristics and has been commercially exploited is *Harumanis cv.* (Faridah, Rosidah, & Jamaliah, 2010). *Harumanis cv.* is also known as the “King of Mangoes” and very well-liked in Malaysia

due to its deliciousness, sweetness and aromatic fragrance. This cultivar is distinctive to Perlis and known in the national agenda as a specialty fruit from Perlis for the world with the total yield of RM41,986,500 with 1825.5 tons in 2017 (Malaysia Fruit Crop Statistics, 2017). As stated by Information Marketing Department of FAMA in 2019, this fruit sales have been reached up to an average of RM38.65 per kilogram in 2016 (Information Marketing Department of FAMA, 2019). Perlis' soil and climatic conditions makes it extremely suitable for *Harumanis cv.* It requires a significant dry weather period to trigger the flowering stage and the productive phase can be significantly affected by changes in weather. *Harumanis cv.* is a yearly fruit bearing tree type and reproductive phase of the *Harumanis cv.* trees usually begins in January and ends in early June. This cultivar is very suitable for the export market as it has favourable colour, sweetness and excellent eating quality with good aroma. Table 1.1 shows number of exported *Harumanis cv.* from Perlis to Japan in 2010 which is aimed to increase at 100 metric tons in 2020 (Farook et al., 2011) and this obviously revealed that *Harumanis cv.* has a high demand in market. As export of fruits is incredibly dependent on quality, the government has constructed a rigid quality control regulation for the export of this fruit since poor conditions of fruits may lead to the rejection and definitely causes market loss (Jha et al.,2012). As a consequence, quality control of *Harumanis cv.* plays important role in deciding the export value of the fruit to the world.

Table 1.1 The target and actual export of *Harumanis cv.* mango to Japan (Farook et al., 2011)

Year	Target	Export
2010	3.1 metric tons	500kg
2011	3.1 metric tons	2.4 metric tons
2020	100 metric tons	?

Considered as an exotic fruit and as a perishable product, a good quality *Harumanis cv.* is highly desired and yield a valuable price in the world market. However, they are prone to pests, disease and physiological disorder attack. According to the 2017 report by Malaysia Agriculture Research and Development Institute (MARDI), the expansion of this cultivar is reportedly hindered due to the incidence of internal tissue breakdown or commonly known as ‘*Insidious Fruit Rot*’ (*IFR*) as shown in Figure 1.2. This physiological disorder was reported in Perlis where losses amounting to 80% have been recorded by growers, which resulted in poor fruit quality and thus reduced marketability. Thus, proper non-destructive approaches that able to detect the existence of this internal disorder are much appreciated, which normally requires information from more than one independent sensors. Hence, the possibility of using a multi-sensory data fusion approach in the same practice as the human brain combines the information resulting from multiple senses will be investigated in order to gain a more accurate results. Figure 1.3 shows *Harumanis cv.* sample in good sensory condition.



Figure 1.2 *Harumanis cv.* affected by IFR



Figure 1.3 Healthy *Harumanis cv.* sample