REAL TIME VISUAL SYSTEM FOR STARFRUIT MATURITY INDEX CLASSIFICATION

RAHMAN BIN AMIRULAH

UNIVERSITI TEKNOLOGI MALAYSIA

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RAHMAN BIN AMIRULAH

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Praise to Allah the Almighty

Thanks to my beloved mother, father and lovely wife Noor Asma Binti A'at

Your support gave me the strength

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ABSTRACT

Considering the demand for fresh starfruit becomes higher nowadays, an automatic system for starfruit quality inspection is mostly needed since the quality inspection of starfruit is still manually performed by human. The objectives of this thesis are to develop a real time visual system and to implement the colour maturity algorithm into a Field Programmable Gates Array (FPGA) system for starfruit colour maturity classification. Generally, the system designed in this work consists of three main sub-systems: input, process and output. The input of the system is acquired by using a digital camera with YCbCr format. The second part of the system is the main processing system which is FPGA. The processes on the FPGA can be divided into three parts, which are segmentation, feature extraction and classification. The segmentation process is utilised to determine the Region Of Interest (ROI) of the starfruit area by using fixed threshold value based on Cb component. The feature fed to the system is extracted from Cr component that becomes the input to the proposed rule-based classifier. In this work, the starfruit is classified into 6 maturity levels. The performance of the proposed system achieved 89% of starfruit correctly classified.

ABSTRAK

Memandangkan permintaan untuk buah belimbing segar telah meningkat pada masa kini, suatu sistem automatik untuk pemeriksaan kualiti buah belimbing adalah amat diperlukan kerana pemeriksaan kualiti buah belimbing masih lagi diproses secara manual. Objektif tesis ini adalah untuk membangunkan sistem visual masa nyata dan mengaplikasikan algoritma warna kematangan pada *Field Programmable Gates Array* (FPGA) yang bermaksud Tatasusun Get Boleh Aturcara Medan untuk tujuan pengkelasan buah belimbing mengikut tahap warna kematangan. Secara umumnya, sistem yang direka ini terdiri daripada tiga sub-sistem utama: masukan, proses dan keluaran. Masukan sistem diperolehi daripada kamera digital dalam bentuk format YCbCr. Bahagian kedua sistem ini ialah sistem pemprosesan utama iaitu FPGA. Proses di dalam FPGA terbahagi kepada tiga bahagian iaitu penemberengan, pengekstrakan ciri dan pengkelasan. Proses penemberengan secara nilai ambang tetap pada komponen Cb digunakan untuk menentukan kawasan yang diliputi buah belimbing. Ciri untuk sistem ini pula diekstrak daripada komponen Cr di mana data ini digunakan sebagai masukan kepada pengelas berasaskan peraturan yang dicadangkan dalam tesis ini. Kerja ini mengelaskan buah belimbing kepada enam jenis tahap kematangan. Prestasi sistem menunjukkan 89% buah belimbing telah dikelaskan dengan tepat.

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LIST OF ABBREVIATIONS

GUI	-	Graphic User Interface
MSE	-	Minimum Square Error
MMSE	-	Minimum Mean Square Error
RGB	-	Red, Green, Blue
HSI	-	Hue, Saturation, Intensity
CYMK	-	Cyan, Yellow, Magenta and Black
L*a*b	-	Lightness, +magenta -green, +yellow -blue
YCbCr	-	Digital – Y(Luminance), Cb(Blue difference), Cr(Red Difference)
YPbPr	-	Analog– Y(Luminance), Pb(Blue difference), Pr(Red Difference)
SRBRE	-	Self-Regulated by Regulated Entities
FAMA	-	Federal Agricultural Marketing Authority
FPGA	-	Field Programmable Gates Array
PC	-	Personal Computer
NIR	-	Near Infra Red
NIRS	-	Near Infra Red Spectroscopy
SSC	-	Soluble Solid Content
FIS	-	Fuzzy Inference System
MLR	-	Multiple Linear Regression
ANN	-	Artificial Neural Network
S	-	Small
M	-	Medium
L	-	Large
XL	-	Extra Large
ROI	-	Region of Interest
DSP	-	Digital Signal Processing

ASICs	-	Application-Specific Integrated Circuits
CCD	-	Charge-Coupled Device
HDL	-	Hardware Description Language
TV	-	Television
LCD	-	Liquid Crystal Display
CMOS	-	Complementary-Symmetry Metal–Oxide–Semiconductor
SoC	-	System on Chip
DMA	-	Direct memory access
USB	-	Universal Serial Bus
fps	-	Frame per Second
SDRAM	-	Synchronous Dynamic Random-Access Memory
mbps	-	Mega bit per second
VGA	-	Video Graphic Audio
DAC	-	Digital Analog Converter
MHz	-	Mega Hertz
NTSC	-	National Television System Committee
PAL	-	Phase Alternating Line
SECAM	-	Sequential Colour with Memory
DVD	-	Digital Video Drive
ITU	-	International Telecommunication Union
VHDL	-	VHSIC hardware description language
LEs	-	Logic Elements
DMUX	-	Demultiplexer
FIFO	-	First In First Out
JPEG	-	Joint Photographic Experts Group
HD	-	High Definition
nm	-	nanometer

LIST OF SYMBOLS

R	-	Red
G	-	Green
B	-	Blue
Y	-	Luminance
Cb	-	Blue Difference
Cr	-	Red Difference
H	-	Hue
m	-	Simplified Hue (RG)
M	-	C_r Feature
C	-	Starfruit range of possible Hue values
A	-	Area
i	-	Index Number
$E_{\Lambda,H,i}$	-	Class Error
j	-	Number of pixel

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CHAPTER 1

INTRODUCTION

1.1 Background of Study

Carambola or starfruit is believed originally from Sri Lanka or Moluccas, Indonesia. However, the starfruit has been spread to Asian country for hundred years. The fruit is showy, oblong and has a uniform and symmetric shape with five longitudinal ribs. Cutting across, it will form a star-shaped section that gives rise to the common name “starfruit” such as shown in Figure 1.1 [1].

Figure 1.1: Examples of Starfruit Images

Starfruit is one of the popular fruits exported around the world from Malaysia since 1989 [2]. This is why starfruit is a special product where it is not only popular among Malaysians but also to the worldwide nations. To ensure the quality of the export, since 1965 starfruit production is controlled and monitored by a government body called Federal Agricultural Marketing Authority (FAMA) [3]. Specifically, FAMA is a marketing agency established by the Malaysia government under Ministry of Agriculture and Agro-based Industrial [3]. Based on export statistic published by FAMA, in 2008 there were about 2711 metric ton of starfruit, which is equivalent to about RM 25.5 million was exported to various countries over the world, such as European countries (Netherlands, France, Germany, Canada), Middle East Countries (Saudi Arabia, Iran, Bahrain, Turkey), and Asian countries (Singapore, Hong Kong, Indonesia). European countries were the major markets for the Malaysian starfruits covering almost 97% of the overall exports. The 2008 annual statistics for starfruit export was increased by 7.58% to 2711 tons comparing to 1239 tons in 2007 [4]. Until Jun 2009, the export recorded about 901.509 metric tons (RM14.5 million) of starfruit has been exported from Malaysia [5]. These export figures tells that starfruit is among the great commodity which are able to generate income to Malaysian economy.

The fresh starfruit products exported from Malaysia are well known in Europe countries because of its good quality which normally rated by its taste and physical appearance. Thus, Malaysia was acknowledged to have the best taste compared to other exporter countries [6]. However, the attractiveness of the physical appearance of the starfruit is much important as its taste. In order to maintain these qualities, a quality label called Malaysia's Best was created by FAMA [7]. Figure 1.2 shows the Malaysia's Best quality label for the export fruit from Malaysia. Under this label, every step from harvesting to packaging of the fruit is described to ensure the quality. However, the process of inspecting the quality of the starfruit can be performed either by FAMA or the farm owner which have a license granted by FAMA to do the inspection. This licensing programme is called Self-Regulated by Regulated Entities (SRBRE) [8].

Figure 1.2: Malaysia's Best Label

Until today, the evaluation of the starfruit quality is still in its traditional method where it is performed manually by humans [9]. The disadvantage of this manual operation is time consuming while the accuracy of the operation cannot be guaranteed due to human nature such as fatigue. The effectiveness of this manual technique depends on the expertise, experience and high concentration of the operator. Hence moving towards automatic evaluation should solve the problems.

In order to guaranty the quality evaluation process under the Malaysia's Best label, the starfruit quality evaluation label has been standardized under Malaysian Standard (MS1127) in year 2002 [10]. Based on the Malaysian Standard, the grade for fresh starfruit can be divided into three different grades which are Grade Premium, Grade 1, and Grade 2. Details on the specification of the grades are shown in Table 1.1. Based on Table 1.1, the physical appearance for the starfruit quality are divided into five important criteria's which are uniform in maturity, freshness, free from defects, free from damages and uniform in size. Among those criteria's, the maturity uniformity of the starfruit is the main interest for this thesis.

Table 1.1: Starfruit Grade Specification referring to Malaysian Standard, Specification for Fresh Carambola MS1127:2002

Grades	Requirements	Tolerance
Premium	The fruit shall be clean, firm, well- formed, uniform in size and free from blemishes and discolourations with the exception of very slight superficial defects in the skin and ribs due to rubbing and bruises provided that these do not affect the general appearance of the produce, the quality, the keeping quality and presentation in the package.	Fruit which do not meet these requirements should not exceed 5 % by count or weight but shall conform to the requirements of the next lower grade.
1	The fruit shall be clean, firm, fairly well-formed and fairly uniform in size. They shall be reasonably free from discolourations and blemishes provided that these do not affect the general appearance of the produce, the quality, the keeping quality and presentation in the package. The total surface area affected shall not exceed 5 %.	Fruit which do not meet these requirements should not exceed 10 % by count or weight but shall conform to the requirements of the next lower grade.
2	The fruit shall be reasonably clean, firm, fairly well-formed and fairly uniform in size. They shall be reasonably free from discolourations and blemishes provided that the fruit retain its essential characteristic as regards to the quality, the keeping quality and presentation. The total surface area affected shall not exceed 10 %.	Fruit which do not meet these requirements should not exceed 10 % by count or weight.

Maturity of the fruit is very important where normally abroad customer will choose starfruit with good physical appearance which defined based on uniform maturity and minimum defect. Physical appearance is also important because these customers are not able to taste the whole starfruit on the market [11]. Thus, the best way is to select the starfruit based on the physical appearance. Besides, the sweetness of the starfruit can be estimated based on the maturity level of the starfruit [12] and the maturity level can be determined via the starfruit skin colour. Mature starfruit will have orange colour with a little yellow and for immature starfruit, it is in green colour. Thus, this is why it is the normal practice for the abroad customers to buy the starfruit based on the maturity level of the starfruit.

By knowing the starfruit maturity, the farmer can also separate the fruit nicely according to its maturity level so that the starfruits can be packed at similar maturity level. For export purpose, the starfruit is packed not only based on its maturity, but also on similar size and weight [13]. Other than that, the maturity level is also use to determine the transportation method, whether via the sea or via the air. For example, the mature fruit is not suitable to be transported via sea because the sea transportation needs a long time to arrive at its destination.

1.2 Starfruit Maturity

In the starfruit maturity process, the starfruit skin changes from dark green colour into orange colour where dark green colour is for immature starfruit while the orange colour is for very mature starfruit. Based on the Malaysian Standard mention previously, the starfruit maturity can be classified into 7 levels of maturity, namely index 1 to index 7. Index 1 is for the most immature starfruit and change towards index 7 for the most mature starfruit.

In previous maturity classification standard, it was only 6 maturity levels. Just then it was reviewed to 7 indexes in June 2006 [14]. However, the previous 6 index are still in use at most farm and still acceptable for the export purposed. These 6 indexes of starfruit are shown in Table 1.2. For this work, the 6 index version is considered as most of current practice is still based on the 6 index.

Table 1.2: Starfruits Index

 Index 1	**Dark Green** Fruit is immature. Not suitable for harvesting or exporting.	 Index 2	**Green with a little yellow** Matured. Suitable for harvesting and export trough sea.
 Index 3	**Green more than yellow** Matured. Suitable for harvesting and export trough sea.	 Index 4	**Yellow green** For export using air transport.
 Index 5	**Yellow with a little green** Still can be sent for far export using air transport.	 Index 6	**Orange** Not suitable for far export. Local market only.

1.3 Problem Statement

Up to present, the starfruit quality inspection is still performs manually using human labour, which is prone to error and inefficiency due to the human subjective nature. Because of this reason, the development of an algorithm for the starfruit maturity classification was developed by several researchers such as in [15][16]. In [15], a novel technique has been introduced where one colour feature was implemented instead of normal three colour features. However, the algorithm is not yet to be implemented on the hardware system. The implementation and evaluation of this algorithm were performed only via computer software called MATLAB as an offline system.

In the previous topic, the quality inspection process can be performed by the farm owner who has the SRBRE licence. These farmers normally performing the quality inspection process on their own farm, which has limited supply for electrical power. Thus, for those who performed the SRBRE for the starfruit quality inspection process, there is a need for low power system with low cost development (Less than RM20,000) and maintenance.

Therefore, this research work will focus on the implementation of the maturity classification algorithm developed in [15] on a machine vision system. As for the system development, this work will consider the low power processing devices with low maintenance cost and minimum development cost that suitable for the farmer performing the SRBRE quality inspection process.

1.4 Objectives

The objectives of this research project are to:

1. Develop a real time visual system for starfruit quality inspection.
2. Implement the starfruit colour classification algorithm on Field Programmable Gates Array (FPGA).

1.5 Scopes

As shown in Table 1.2, only few maturity indices of the starfruit can be exported either via sea transportation or air transportation. For starfruit classified as index 1, it cannot be considered for harvesting or exporting because it is immature. The starfruit that can be exported via sea transportation must be in variance of index 2 and index 3, while starfruit with index 4 and index 5 can still be exported but restricted via air transportation only. Index 6 is for local market only. The starfruit colour maturity algorithm implemented in this work will be able to classify the starfruit up to index 6.

1.6 Research Methodology

The work undertaken in this research can be separated into two parts which are hardware development and algorithm implementation.

The hardware development in this work are includes designing and building illumination chamber and conveyor system such shown in Figure 1.3. The illumination chamber is used to control the illumination when capturing the starfruit image while the conveyor system is developed so that real condition on the starfruit processing can be achieved.

As for the algorithm implementation, the algorithm for starfruit colour classification is taken from [15]. The algorithm developed in [15] is used as the original algorithm where the algorithm is modified in this work. The modification of the algorithm is to derive the original algorithm to suit with the system which using YCbCr colour space in the image data processing. The software used to implement the algorithm into FPGA is Altera Quartus II software design.

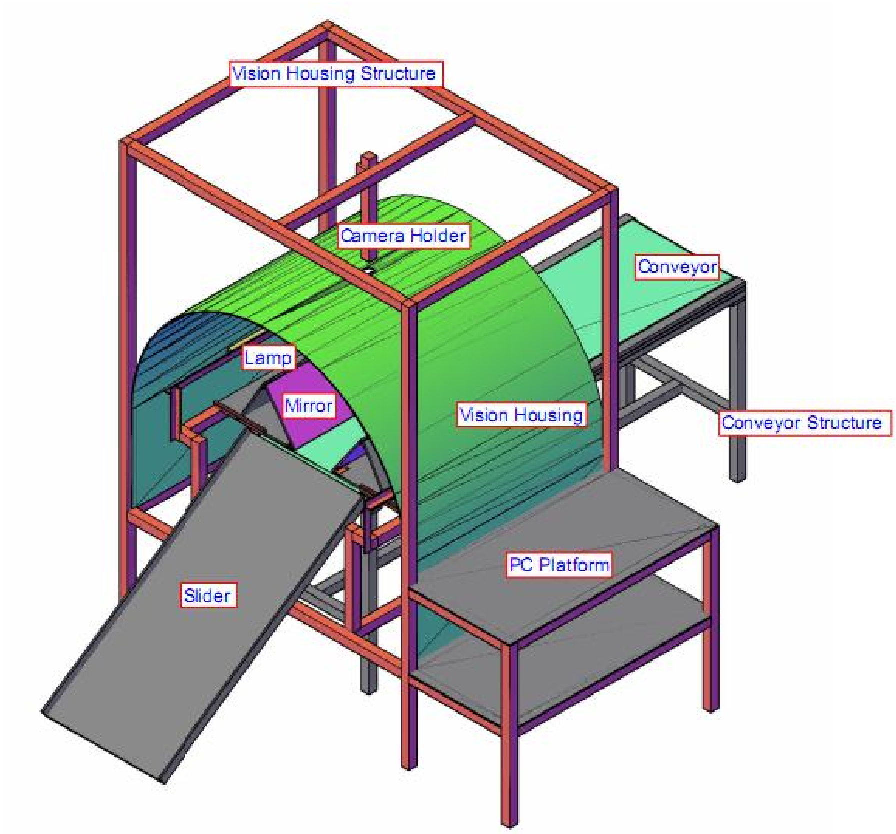

Figure 1.3: The Proposed Conveyor and Illumination Chamber

1.7 Project Contributions

This work is to implement the starfruit colour classification algorithm into machine vision system based on FPGA as the main processing system. To implement the starfruit colour classification in FPGA, the knowledge to develop a system for controlling the image data from a camera device is needed. The data from colour camera must be stored first in temporary memory before the data used in classification process. Controlling the image data using FPGA as the main processing for the system is quite challenging especially when the algorithm has multiplication and division process. One of the challenging tasks in the algorithm implementation is when the sign of the number becomes negative which need 2nd compliment in binary. The conversion of negative sign number using 2nd compliment makes the system speed slow down. The solution on this challenge is to avoid the calculation that gives negative number in the system.

The algorithm implemented in this work is a modified version from the original algorithm where single chrominance component based on HSI colour space was derived. First, derivation of the original algorithm (Hue) into YCbCr colour space is made as the camera used in this work is based on YCbCr colour space. Then, the derived colour features is simplified which result less calculation where the feature is extracted directly from a single component of Cr. Not only the algorithm becomes simpler, the algorithm is more suitable to the main processing system where all the hue values are now positive values compare to the previous single Hue algorithm which involves both positive and negative values.

Another contribution is developing the hardware which is the conveyor system in order to transfer the starfruit into the vision chamber for the classification process. The conveyor is developed with variable speed and lighting system with illumination control. The starfruit is detected using camera data pixel and the image will be captured when the starfruit is within the image region.

1.8 Thesis Organization

This thesis is organized into six chapters. The first chapter introduces the background of the study, the starfruit quality inspections process, the starfruit colour maturities, the problem statements, objectives, scopes, research methodology and research contribution of the work.

Second chapter discussed related and existing systems for fruit grading. This chapter starts with the topic on grading criteria for fruit in general that can be divided into two main grading specifications which are non-colour and colour grading. Then, a more detailed discussion on the previous work for the starfruit maturity classification based on colour. To complete the chapter, various colour space applied in the existing fruit grading system and the specifications of the system for machine vision system used in fruit classification are also discussed.

The third chapter discusses about the previous starfruit colour maturity algorithm presented in [15] where it is based on simplified Hue from RG colour components. Comparing to the state of the method proposed by [15], the discussion on the modification of the algorithm into YCbCr colour space is also discussed. The details on the reason behind the modification are also discussed in the chapter.

The FPGA system design architecture is discussed in the fourth chapter. The data flow inside the main processing is also discussed together with the implementation technique applied for the system design. The important task in this research work is the development of implementation code for the FPGA and the mechanical part of the system consisting of the conveyor platform and the vision chamber.

The fifth chapter are the results and discussions of the research. The results are evaluates all experiments that have been performed and the performance of the proposed techniques are discussed in the discussions part.

The final chapter consists of a conclusion in this work. It also described the problems arises and recommendations for future research.

REFERENCES

[1] Asna Booty Othman, Muhamad Hj. Omar and Nuraizah Hashim (2004). *Technical Document For Market Access On Star fruit (carambola).*Crop Protection & Pant Quarantine Services Division, Department of Agriculture, Kuala Lumpur, Malaysia.

[2] Maria J. Dass and Gabrielle Chaik (2005).*Star Attraction*. Cover Stories in Sun2Surf.

[3] Sahbani Saimin, Abd. Ghariff Ramin, Sebastian Chew and Mohd. Hafiz Mohd. Adnan (2008).Market Price Watch and FAMA's Role In Malaysian Agricultural Marketing. *Asiaand Pacific Commission On Agricultural Statistics (APCAS).Twenty-second Session*. 9-13 June 2008.Kuching, Sarawak, Malaysia.

[4] Federal Agricultural Marketing Autority (FAMA) (2009). *Annual Trade Report*. Website: *http://www.famaxchange.org/web/guest/tredestatistic*.

[5] Mohd Hamirol Ab Hamid (2009). *Quantity and Export Value of Fruits by Country for 2004 until June 2009.* FAMA Johor Malasia ,14 Oct 2009.

[6] Jonathan H. Crane (1993).Commercialization of Carambola, Atemoya, and Other Tropical Fruits in South Florida. *Proc. of the 2nd National Symp. On Exploration, Research & Commercialization*. New York: New crops. Wiley. 448-460.

[7] Tom Bicknell (2009).Room for Malaysian exports?.*ASIAFRUIT Magazine*. May / June 2009. p. 52.

[8] Federal Agricultural Marketing Authority (FAMA), *Annual Report*, 2009.

[9] M. M. Mokji and S.A.R. Abu Bakar (2006). Starfruit Grading Based on 2-Dimensional Colour Map. *Regional Postgraduate Conference on Engineering and Science (RPCES)*.26-27 July 2006. Johore: Universiti Teknologi Malaysia. 203-206.

[10] Malaysian Standard (2002). *MS1127 Specification for Fresh Carambola*. Malaysia:Malaysian Standard.

[11] Food and Agriculture Organization (FAO) of the United Nations (2009).*Fruit and Vegetable Processing*. Agribusiness Handbook. Rome, Italy:Investment Centre Division.

[12] M.L. Roose and T.E. Williams (2006).*'Gold Nugget' Mandarin*. Department of Botany and Plant Sciences, University of California, Riverside.

[13] *http://www.itfnet.org/gfruit/Templates%20English/carambola.harv.post.htm*

[14] Federal Agricultural Marketing Authority (FAMA) (2006).*Manual Quality Series "CARAMBOLA"*. [Brochure]. Selangor:FAMA.

[15] Musa Bin Mohd Mokji (2009). *Features Construction for Starfruit Quality Inspection*, Ph.D. Thesis. Universiti Teknologi Malaysia.

[16] M.Z. Abdullah, A.S. Fathinul-Syahir, B.M.N. Mohd-Azemi (2005).Automated inspection system for colour and shape grading of starfruit (Averrhoacarambola L.) using machine vision sensor. *Transactions of the Institute of Measurement and Control*. 27, 2:65-87.

[17] Q. Yang (1995).Automatic Detection of Patch-like Defects on Apples. *Fifth International Conference on Image Processing and its Applications*, 4-6 Jul 1995. Edinburgh: IEEE. 529-533.

[18] M. Recce, J. Taylor, A. Piebe and G. Tropiano (1996). High speed vision-based quality grading of oranges. *International Workshop on Neural Networks for Identification, Control, Robotics, and Signal/Image Processing*.21-23 Aug. 1996. Venice: IEEE. 136-144.

[19] S. Limsiroratana and Y. Ikeda (2002). On image analysis for harvesting tropical fruits. *Proceedings of the 41st SICE Annual Conference*. 5-7 Aug. 2002. Osaka, Japan: IEEE. Vol 2:1336-1341.

[20] Website:*http://www.terengganutourism.com/local_fruits.htm*(FEB 2011)

[21] Mizuki Tsuta, Junichi Sugiyamaand Yasuyuki Sagara (2002). Near-Infrared Imaging Spectroscopy Based on Sugar Absorption Band for Melons, *J. Agric. Food Chem.*50 (1):48–52

[22] A'zraa Afhzan Ab Rahim, Muhammad Syafiq Abdullah Sawal, Mazidah Tajjudin and Ili Shairah Abdul Halim (2011). A Non-invasive Method to Measure the Sweetness of Malaysian Papaya Quantitatively Using NIR Full-transmittance Technique- a Preliminary Study. *Third International Conference on Computational Intelligence, Communication Systems and Networks*. July 26-July 28.Bali, Indonesia: IEEE. 379-384.

[23] Zou Xiaobo and Zhao Jiewen (2005). Apple quality assessment by fusion three sensors. *IEEE Jurnal Sensors*.Oct. 30 - Nov. 3. Irvine, CA:IEEE. 389-392.

[24] Jesús Brezmes, Ma. Luisa López Fructuoso, Eduard Llobet, Xavier Vilanova, Inmaculada Recasens, Jorge Orts, Guillermo Saiz and Xavier Correig (2005). Evaluation of an Electronic Nose to Assess Fruit Ripeness. *IEEE Jurnal Sensors*. 5(1):97-108.

[25] Xu Liming and Zhao Yanchao (2010). Automated strawberry grading system based on image processing. *Computers and Electronics in Agriculture*. 72:32–39.

[26] Nur Badariah Ahmad Mustafa, Nurashikin Ahmad Fuad, Syed Khaleel Ahmed, Aidil Azwin Zainul Abidin, Zaipatimah Ali, Wong Bing Yit and Zainul Abidin Md Sharrif (2008). Image Processing of an Agriculture Produce: Determination of Size and Ripeness of a Banana. *International Symposium on Information Technology*. 26-28 Aug.2008. Kuala Lumpur: IEEE. 1-7.

[27] B.K. Dadzie et J.EOrchard. (1997). *Routine Post-Harvest Screening of Banana/Plantain Hybrids: Criteria and Methods.* International Plant Genetic Resources Institute. France:INIBAP.

[28] C. L. Hsieh and M. H. Lee (2009). Applied Hyperspectral Image on Detecting the Maturity, Weight, and Sugar Content of Tai-Farm No.2 Papaya. *American Society of Agricultural and Biological Engineers.* June 21 - June 24, 2009. Reno, Nevada: Curran Associates, Inc. 392-394.

[29] Dobrzanski B and Rybczynski R (2002). Colour change of apple as a result of storage, shelf-life, and bruising. *International Agrophysics.* 16:261–268.

[30] B. K. Miller and M. J. Delwiche (1989). A colour vision system for peach grading. *Transactions of the ASAE.* 34(4):1484–1490.

[31] D.J. Lee, Yuchou Chang, J.K. Archibald and C.G. Greco (2008). Colour Quantization and Image Analysis for Automated Fruit Quality Evaluation. *IEEE International Conference on Automation Science and Engineering(CASE).*23-26 Aug. 2008.Arlington, VA: IEEE. 194 – 199.

[32] Farah Yasmin Abdul Rahman, Shah Rizam Mohd Shah Baki, Ahmad Ihsan Mohd Yassin, Nooritawati Md. Tahir and Wan Illia Wan Ishak (2009). Monitoring of Watermelon Ripeness Based on Fuzzy Logic. *World Congress on Computer Science and Information Engineering.*20-22 October, 2009.San Francisco, USA: Springer. 67-70.

[33] Meftah Salem M. Alfatni, Abdul Rashid Mohamed Shariff, Helmi Zulhaidi Mohd Shafri, Osama M. Ben Saaed and Omar M. Eshanta (2008). Oil Palm Fruit Bunch Grading System Using Red, Green and Blue Digital Number. *Journal of Applied Sciences.* 8 (8): 1444-1452.

[34] Nursuriati Jamil, Azlinah Mohamed and Syazwani Abdullah (2009). Automated Grading of Palm Oil Fresh Fruit Bunches (FFB) using Neuro-Fuzzy Technique. *International Conference of Soft Computing and Pattern Recognition.* 4-7 Dec. 2009.Malacca: IEEE. 245 - 249.

[35] P. Sudhakara Rao, A. Gopal, R. Revathy and K. Meenakshi (1999). Colour Analysis of Fruits Using Machine Vision System for Automatic Sorting abd Grading. *Jurnal Instrum. Soc. India*. 34 (4):284-291.

[36] M.Z. Abdullah, J. Mohamad-Saleh, A.S. Fathinul-Syahir and B.M.N. Mohd-Azemi (2006). Discrimination and classification of fresh-cut starfruits (Averrhoa carambola L.) using automated machine vision system. *Journal of Food Engineering*. 76:506–523.

[37] S.P. Kang, A.R. East and F.J. Trujillo (2008). Colour vision system evaluation of bicolour fruit: A case study with 'B74' mango. *Postharvest Biology and Technology*. 49:77–85.

[38] W. Md. Syahrir, A. Suryanti and C. Connsynn (2009). Colour Grading in Tomato Maturity Estimator using Image Processing Technique. *2nd IEEE International Conference on Computer Science and Information Technology*(*ICCSIT)*. August 08-August 11. Beijing, China: IEEE. 276 – 280.

[39] Hongpeng Yin, Yi Chai, Simon X. Yang and Gauri S. Mittal (2009). Ripe Tomato Extraction For A Harvesting Robotic System. *Proceedings of the International Conference on Systems, Man, and Cybernetics San Antonio*. 11-14 Oct. 2009. TX, USA: IEEE. 2984 - 2989.

[40] Shah Rizam M. S. B., Farah Yasmin A.R., Ahmad Ihsan M. Y. and Shazana K (2009). Non-destructive Watermelon Ripeness Determination Using Image Processing and Artificial Neural Network (ANN). *International Journal of Computer Systems Science and Engineering*. 4(6):391-395.

[41] W.S. Lee, R. Chinchuluun and R. Ehsani (2009).Citrus fruit identification using machine vision for a canopy shake and catch harvester. *Acta Horticulturae*. Vol. 824: 217-222.

[42] Jaskaran Singh. *ROBOT VISION*, Submitted in Partial Completion of the Requirements of IEM 5303 Advanced Manufacturing Systems Design, Fall 2000.

[43] Moisés Rivas López, Oleg Sergiyenko and Vera Tyrsa. Machine Vision: Approaches and Limitations. Source: Computer Vision, Book edited by: Xiong Zhihui, ISBN 978-953-7619-21-3, pp. 538, November 2008, I-Tech, Vienna, Austria.

[44] Tadhg Brosnan and Da-Wen Sun (2002).Inspection and grading of agricultural and food products by computer vision systems—a review. *Computers and Electronics in Agriculture*. 36(2–3):193–213.

[45] Zhen Jia, Arjuna Balasuriya and Subhash Challa (2009). Vision Based Target Tracking for Autonomous Land Vehicle Navigation: A Brief Survey. *Recent Patents on Computer Science*.2():32-42.

[46] J. Blasco, N. Aleixos and E. Molto (2003). Machine Vision System for Automatic Quality Grading of Fruit. *Biosystems Engineering*. 85(4):415–423.

[47] B.S. Bennedsen and D.L. Peterson (2005). Performance of a system for apple surface defect identification in near-infrared images. *Biosyst. Eng.* 90(4): 419-431.

[48] T. Brosnan and D.W. Sun (2004).Improving quality inspection of food products by computer vision - a review. *Jurnal Food Engin.* 61(1): 3-16.

[49] J.A. Throop., D.J. Aneshansley, B.L. Upchurch and B. Anger. Apple orientation on two conveyors: performance and predictability based on fruit shape characteristics. *Trans. ASABE*. 2001. 44(1): 99-109.

[50] V. Leemans, H. Magein and M.F. Destain (2002).On-line fruit grading according to their external quality using machine vision. *Biosyst. Eng.* 83(4): 397-404.

[51] Daniel Young Reese (2008).*Whole Surface Image Reconstruction for Machine Vision Inspection of Fruit*. Master Degree. University of Maryland.

[52] Jefri Mustapa, Ahmad Zuri Sha'ameri, Muhammad Mun'im Zabidi, *Reconfigurable Embedded Vessel Classification System for High Frequency Telemetry Application*, Faculty of Electrical Engineering, Universiti Teknologi Malaysia, Skudai 81300, Johor, Malaysia, 2009.

[53] Mandeep Kaur and Kulbir Singh (2011).Implementation and performance analysis of Video Edge Detection system on Multiprocessor Platform. *International Journal of Advanced Computer Science and Applications (IJACSA)*. 2(5): 63-70.

[54] Mukul Shirvaikar and Tariq Bushnaq (2009).A Comparison between DSP and FPGA Platforms for Real-Time Imaging Applications. *Proc. of SPIE-IS&T Electronic Imaging, Real-Time Image and Video Processing.* University of Texas, Tyler:SPIE.7244(06):1-10.

[55] Surinder Pal Singh (2004). *Satisfiability Application-Dependent Testing of FPGA using Quantum Computing.* Master Degree. Thapar Institute of Engineering and Technology, Patiala.

[56] C. Fernandez, P. J. Navarro, J. Suardiaz, M. Jimenez and A. Iborra (2005).High-speed and Cost Effective Machine Vision System within the Industry of Preserved Vegetables. *Conference on Machine Vision Applications*. 16-18 May 2005. Tsukuba Science City, Japan: IAPR. 372-375.

[57] Pushpinder Kaur (2006).*Implementation Of Low Power Viterbi Decoder On FPGA.* Master Degree. Thapar Institute of Engineering and Technology, Patiala.

[58] S. Brown and J. Rose (1996). Architecture of FPGAs and CPLDs: A Tutorial. *IEEE Transactions on Design and Test of Computers.* 13(2):42–57.

[59] Dale Ferriere, *A Glimpse Into the Future: Designing Infrastructure with Ambient Intelligent*, ECE994 –PsoC (Programmable System on a Chip) Global Network Academic Test (GNAT), 2005.

[60] B. Draper, W. Najjar, W. Bohm, J. Hammes, B. Rinker, C. Ross, M. Chawathe and J. Bins (2000). Compiling and optimizing image processing algorithms for FPGAs. *Proceedings Fifth IEEE International Workshop on Computer Architectures for Machine Perception.* 11 Sep 2000-13 Sep 2000. Padova. 222 – 231.

[61] T. Nelson (2000).*Implementation of image processing algorithms on FPGA hardware*. Masters Degree. Vanderbilt University, Nashville, TN.

[62] Altera Cooperation, *Introduction to the Quartus® II Software Version 10.0*, www.altera.com, 2010.

[63] Richard Munden, *A Comparison of VHDL and Verilog Resource Usage by Behavioral Memory Models*, Free Model Foundry www.FreeModelFoundry.com, Copyright 2007.

[64] Keith Jack (2007). *Video Demystified: A Handbook for the Digital Engineer*.(Fifth Edition) Elsevier Inc.

[65] Adrian Ford and Alan Roberts (1998).*Colour Space Conversions*.(Report Paper). University of Westminster.

[66] C.I.Chang, Y.Du, J.Wang, S.M. Guo and P.D. Thouin (2006).Survey and Comparative Analysis of Entropy and Relative Entropy Thresholding Techniques. *IEEE Proceedings on Vision, Image and Signal Processing*.153(6): 837-850.

[67] Mohamed Khalil Hani (2007).*Starter's Guide to Digital Systems VHDL & Verilog Design*. (Edition). Universiti Teknologi Malaysia:Pearson Prentice Hall.

[68] Terasic, *DE2-70 User Manual, TV Decoder Specification*, www.terasic.com, 2009.

[69] Data Sheet, *ADV7180 10-Bit, 4× Oversampling SDTV Video Decoder,* Analog Devices, 2006-2010.

[70] Guy Lewis and Michael Waidson, *A Guide to Standard and High-Definition Digital Video Measurements*, www.tektronix.com/video_audio, 2007.

[71] Maxim Integrated Products, Inc. *Video Design Guide: Products to complete the video signal chain*, www.maxim-ic.com/Video, 2009.