PINEAPPLE DISTRIBUTION CLASSIFICATION USING RGB AND FUZZY

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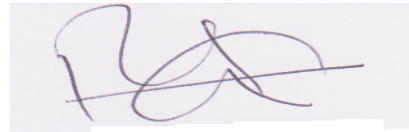
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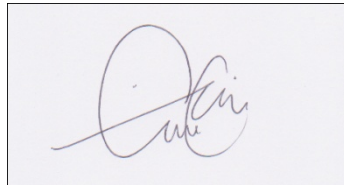PINEAPPLE DISTRIBUTION CLASSIFICATION USING RGB AND FUZZY

EZRIN TASNIM BIN ABDUL GANI

This thesis is submitted as partial fulfillment of the requirements for the award of the

Bachelor of Electrical Engineering (Electronics)

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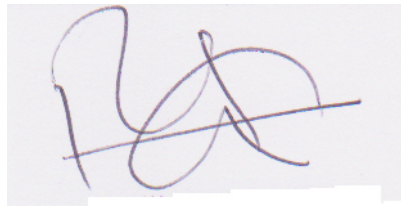
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Specially dedicated to

My beloved parents

"I hereby acknowledge that the scope and quality of this thesis is qualified for the award of the Bachelor Degree of Electrical Engineering "

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Name   : <u>ROHANA BINTI ABDUL KARIM</u>

Date   : <u>29 NOVEMBER 2010</u>

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ABSTRACT

The aim of this study is to classify pineapple distribution based on RGB technique and fuzzy logic as classifier. Nowadays, the grading of pineapple for export is using manual inspection is not very effective and will misjudgement due to mistake of classify the maturity index by labour workers. These applications of classifier pineapple maturity index are fully automated by using RGB technique and Fuzzy logic. The RGB color technique is utilized as the extracted features for the pineapple rind. Further, the extracted feature is classified using fuzzy logic system to determine the maturity level of the pineapple and the distribution mean. The result for this project is 89% accuracy in color identification process which can improve the grading pineapple system with this technique.

ABSTRAK

Tujuan projek ini adalah untuk mengklasifikasikan pengedaran nanas berdasarkan teknik RGB dan logik fuzzy sebagai pengkelasan. Pada masa kini, penggredan nanas untuk eksport menggunakan pemeriksaan manual sangat tidak berkesan dan akan tersalah disebabkan oleh kesilapan mengelas tahap kematangan buah nenas. Aplikasi indeks pengklasifikasi nanas ini beroperasi sepenuhnya secara automatik dengan menggunakan teknik RGB dan logik fuzzy. Teknik warna RGB digunakan untuk mengekstrak ciri-ciri yang dihasilkan pada kulit nanas. Selanjutnya, cirri-ciri dihasilkan dikelaskan menggunakan sistem logik fuzzy untuk menentukan tahap kematangan dari nanas serta purata untuk memasarkan. Keputusan untuk projek ini adalah 89% ketepatan dalam proses kerana pengenalan warna yang dapat meningkatkan sistem grading nanas dengan menggunakan teknik ini.

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LIST OF SYMBOLS

m	mass of trolley (kg)
m_1	mass of the Hook (kg)
m_2	mass of the Payload (kg)
x	Trolley Position (m)
F	Force apply to the trolley (N)
θ_1	hook swing angle (rad)
θ_2	payload swing angle (rad)
l_1	length of the pendulum at hook (m)
l_2	length of the pendulum at load (m)
g	gravity acceleration (m/s^2)
$\boldsymbol{g}$	gravity effect
$\boldsymbol{q}$	state vector
$\boldsymbol{\tau}$	control vector
ω_n	natural frequency
ζ	damping ratio
A	amplitude of the impulse
t_0	time location of the impulse

LIST OF ABBREVIATIONS

RGB	Red Green Blue
HSV	Hue, Saturation and Value
FAMA	Federal Agricultural Marketing Authority
FIS	Fuzzy Inference System
CCD	Charged Coupled Device
MATLAB	Matrix Laboratory

CHAPTER 1

INTRODUCTION

1.1   Introduction

As in the world globalize era, the technology gets more and more advanced, the technology make us easier in our personal lives in every area. Agriculture also has step up to a new modern technology. It is because agriculture products are highly demanded in today's market. In order to fulfill customer satisfaction, it is necessary to ensure, monitor and control the final product quality for them. In fruit industry, the most crucial factor to determine and verify the quality of a product is based on the fruit maturity index. So, this quality must be grading accurately using the best method. New and modern technology will make this grading method better, simple and easy.

Pineapple (*Ananas comosus*) is the common name for an edible tropical plant and also its fruit (although technically multiple fruit merged together, and perceived as one)[1]. It is native to Paraguay and the southern part of Brazil [2] and nowadays also grown in several parts of Malaysia. This herbaceous perennial plant grows to 1.0-1.5m tall with 30 or more trough-shaped and pointed leaves which surround a thick

stem. The pineapple fruit is eaten fresh or canned and is available as a juice or in juice combinations [3]. According to Federal Agricultural Marketing Authority (FAMA), Malaysia is the top ten world best pineapple and also top pineapple export in 2006 and 2007. It is because FAMA launched Malaysia's Best label as a benchmarking for the quality fruits. This benchmarking is for all fruits and required to be graded and inspected according to Malaysia's Best quality [4].

There are many specifications for graded fruits such as size, appearance and maturity index. Maturity index is the level of ripeness includes shape, color and texture. The old fashion method for maturity inspection is using the human expert employee to check pineapple one by one. This method will lead to some error due to human fault.

1.2   Problem Statement

Nowadays, the grading of pineapple for export is using manual inspection is not very effective and will misjudgment. So, we present this application of classifier pineapple maturity index that can be fully automated by using RGB technique and Fuzzy logic.

1.3   Project Objective

i.   To analyze the best fuzzy structure for grading pineapple.

ii.   To classifier the yellowish of pineapple according to the index maturity.

iii.   To develop algorithm for grading the maturity pineapple according to index maturity.

1.4   Scope of project

1. In this project, there are two type of sample in order to create multiple pineapples from different area.

    i.   Simpang Renggam, Johor

2. Type of pineapple is one of the most factor in this project.

    i.   Joshapine

1.5   Thesis Outline

Chapter 1 contains explanation on the introduction of the project which consists of the overview of the problem statement, objectives, and scope of image colour detection project.

Chapter 2 is more focused on literature review which is the research and studies of this project.

Chapter 3 views the methods that are used in completing the project from the beginning to the end. This includes project's flow, analysis, and all programming used in this project.

Chapter 4 present the full simulation of project for the maturity index of pineapple.

Chapter 5 shows all the analysis and result from the simulation and calculation that have been compute.

Chapter 6 concludes the overall of the project and which includes the problem and future recommendation for project in future development. The costing and commercialization issue will also be discussed here.

CHAPTER 2

LITERATURE REVIEW

2.1   Color Space

A color space is defined as a model for representing color in terms of intensity values [1, 2]. Typically, a color space defines a one- to four-dimensional space [3]. A color component, or a color channel, is one of the dimensions. A color dimensional space (one dimension per pixel) represents the gray-scale space. In general, there are two models are commonly use in color image, that is RGB color model and Hue, Saturation and Value (HSV). But in this project, the RGB color model are chosen to implement in this system because RGB color model are usually use in display image and used most on computer generated image.

2.1.1 RGB color space

The RGB color space is a way of specifying colors based on the mixing of different colors of light. The RGB color space is an additive color space based on RGB color model. A particular color space is defined by the three chromatic of the red, green, and blue additive primaries. The complete specification of this color space is needed a white chromaticity and a gamma correction curve [5].
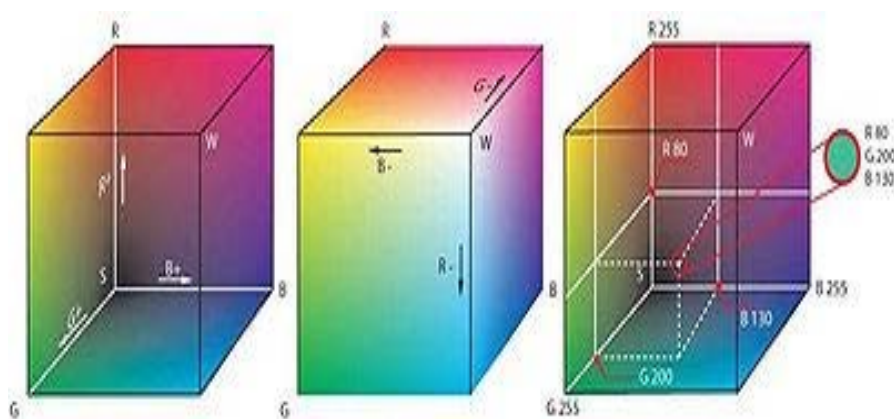
Figure 2.1: RGB cube

The RGB color space easily understood by thinking of all possible color where it made from three colorants that is red, green and blue. RGB are convenient color model for computer graphic because the human vision system works in a way that is similar to RGB color space.

2.2   RGB Color Model

From the color space, it was based on RGB color model. The RGB color model is composed of the primary colors Red, Green, and Blue. They are considered the "additive primaries" since the colors are added together to produce the desired color [1,3]. In color segmentation the RGB color space is most commonly used where each color is represented by a triplet red, green and blue intensity [10].

The RGB model uses the Cartesian coordinate system as shown in Figure 2.2. (a). Notice the diagonal from (0,0,0) black to (1,1,1) white which represents the grey-scale. In figure 2.2(b) indicate a view of the RGB color model looking down from "White" to origin.
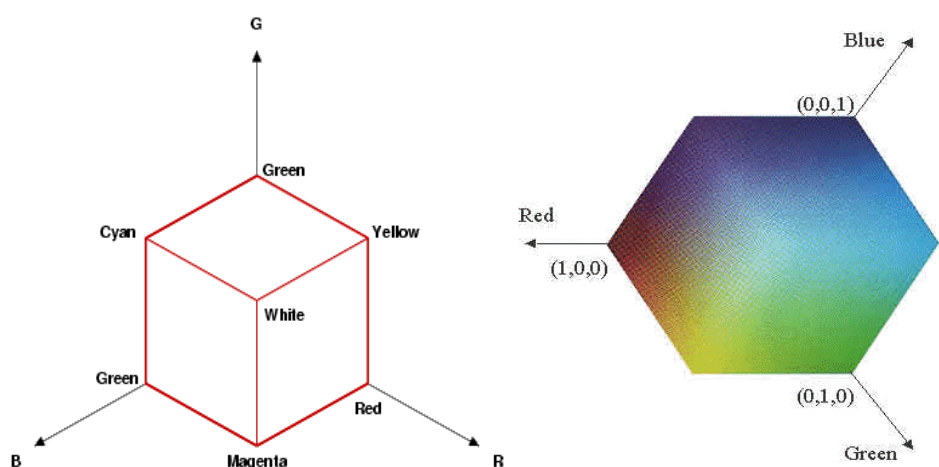
Figure 2.2: RGB model (a) Coordinate system   and (b) view of RGB

RGB is really useful because the yellowish and maturity of pineapple based on the color. Pineapple-skin model is employed and can classify each fruit into one of seven maturity levels by detecting changes in color (from green to yellow) from bottom to top of the fruit. [8].

2.3   Pineapple maturity index

RGB is really useful because the yellowish and maturity of pineapple based on the color. Pineapple-skin model is employed and can classify each fruit into one of seven maturity levels by detecting changes in color (from green to yellow) from bottom to top of the fruit. [8].

According to Malaysia's best standard produced by Federal Agricultural Marketing Authority (FAMA), pineapple maturity index was graded into seven indexes [4].

Index	Specification
Index 1	- young or immature. - The entire surface or sharp points on the oval, dark green with reddish braktea. - The contents are very solid. - Not suitable for picking.
Index 2	- initial maturity. - Eyes slightly more rounded overall dark green with some yellowish between the eyes at the base. - Braktea white and dry. - Contents solid. The fruit can be harvested already. - Suitable for export.
Index 3	- matured. - Whole green eyes with 1-2 points on the base yellow. - Suitable for export.

Index 4	- fruit began to ripe. - Average 25% of the line points from the base turns slightly orange fruit. - Contents solid.
Index 5	- nearly 50% of the eyes become orange yellowish fruit from the base. - Less firm and juicy contents.
Index 6	- over 75% of eyes slightly orange yellowish in color. - Fill a bit soft and a little more juice. - Not suitable for export
Index 7	- ripen. - Whole orange yellowish eyes. - Fill soft and too much juice. - Not suitable for the market.

Table 2.1: List of maturity index

2.4   Drawback of Visual (human) Inspection

The determination of color also can be carried out by visual (human) inspection. Although human inspection is quite robust even in the presence of changes in illumination, the determination of color is in this case, subjective and extremely variable from observer to observer. In order to carry out a more objective color analysis, color standards are often used as reference material. Unfortunately, their use implies a slower inspection and requires more specialized training of the observers [55]. We can see that manual food quality assessment and classification techniques will increases production costs and introduces the potential for human error [6]. Consequently such characteristics have been evaluated by computer vision for example an automated visual inspection of pineapple has also been performed.

It is clear machine should be used and replace human in so many attention as it do not retaliate and do very forward to what being asked for. In industrial application, vision analysis routines test incoming images part quality. Overall, computer vision are more reliable and cost-effective than human workers in the high-speed, detailed, repetitive manufacturing processes required for making semiconductors, electronic, medical, pharmaceutical and computer products.

2.5 Fuzzy Logic

Fuzzy systems, pioneered by Lotfi A. Zadeh in the 1960s, basically deal with how human beings handle imprecise and uncertain information. They mimic how human beings use approximate reasoning in dealing with imprecision, uncertainty, inaccuracy, inexactness, ambiguity, vagueness, qualitativeness, subjectivity, and perception that are experienced in everyday decision making[10]. Fuzzy is the easier system because it is deal with linguistic and perceptions same with human language.

Fuzzy Logic is successful monitor the watermelon ripeness based on research done by Farah Yasmin Abdul Rahman, Shah Rizam Mohd Shah Baki, Ahmad Ihsan Mohd Yassin, Nooritawati Md. Tahir and Wan Illia Wan Ishak (2009) [9]. The accuracy of Fuzzy Logic making decision is more than expected which is 96%. The application of soft computing techniques such as fuzzy logic should be opted for as classifier in the fruit industry.

Fuzzy Rule is really important in this system. It is because making a Rule is like a language to the system for proceed the process to the output. Fuzzy expert systems use fuzzy IF-THEN rules. A fuzzy IF-THEN rule is of the form

IF $X_1 = A_1$ and $X_2 = A_2$ ... and $X_n = A_n$ THEN Y = B

where X_i amd Y are linguistic variables and A_i and B are linguistic terms. The IF part is the antecedent or premise, while the THEN part is the consequence or conclusion. An example of a fuzzy IF-THEN rule is

If the color is greenish, there is no defect, and it is a well formed large apple, then quality is very good.

If the color is pure yellow (overripe), there are a lot of defects, and it is a badly formed (small) apple, then quality is very bad.

This Fuzzy IF-THEN rules [9], is command the system to make a decision using human thinking and language. The Fuzzy system is really easier to control although it is very cheap in terms of cost.

CHAPTER 3

METHODOLOGY

3.1   Introduction

This chapter represents all of methodology for this project. It describes on how these project is organized which is the flow of step in order to complete the project. The methodology is divided into two parts, which are create the pixel range for image and developing the software for processing of the yellowish maturity index color. The other part is developed the fuzzy logic to make the software more stability and accurate according to image pixel mean.

3.2   System Flow

```
           ╭─────────────╮
          (     Start      )
           ╰─────────────╯
                 │
                 ▼
        ┌──────────────────────┐
        │      Pineapple        │
        │   Data acquisition    │
        │  -  Pineapple picture │
        └──────────────────────┘
                 │
                 ▼
        ┌──────────────────────┐
        │    Pre-processing     │
        │  -   Threshold in     │
        │        RGB            │
        └──────────────────────┘
                 │
                 ▼
        ┌──────────────────────┐
        │  Feature Extraction   │
        │  -    Regions Filled  │
        │  -    Masked Image    │
        └──────────────────────┘
                 │
                 ▼
              ╭──────╮
             (    A    )
              ╰──────╯
```
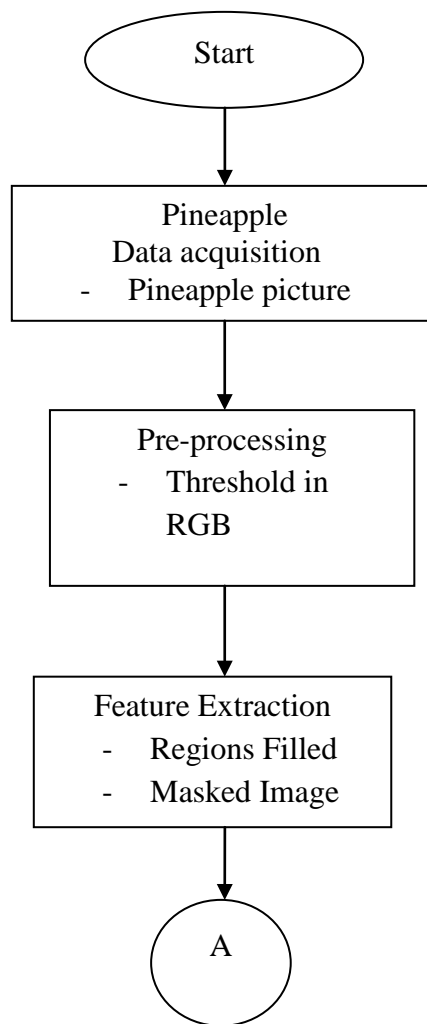
Figure 3.1: Flow chart for a pineapple feature extraction.

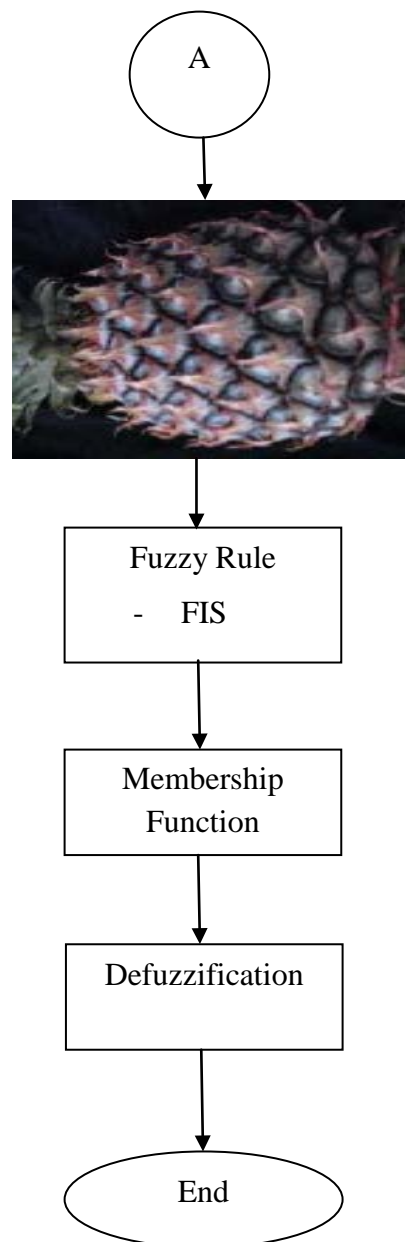The figure 3.2 below show the overall process of fuzzy logic system.

Figure 3.2: Flow chart for Fuzzy Logic Process

3.2.1 Pineapple Data Information

The data and picture of each pineapple index was captured and stored in database. This data was taken from the previous research of RDU08315. There is a location for Joshapine pineapples data which is at Simpang Renggam, Johor. There about 30 pictures of each maturity index have been taken, where each images need to customize the pixel values.

There are many things must be consider while taking the images includes environment factors and distance for capturer. The lighting is most difficult thing need to consider because this factors will produces the different brightness for images. So this data is taken using the same brightness at the same place to reduce this problem.

3.2.2 Pre-processing

In first step, the pre-processing is used for improvise the RGB image that have been captured due to some disturbance and distortion that occurred while collecting the data information. Collecting data by capturing from camera will lead to some noise. From pre-processing, the data information will enhance and the noise has been remove. Thresholding technique is suitable for this process. This technique allow only the setting color which is yellowish for remain in picture. The other color out of setting will return as 0 which means black color. Features background is consider as noise, so this will turn into black because of the threshold value. This method will make the next process easier due to remaining the color of yellowish. The figure in chapter 5 shows the pre-processing step and procedure.

3.2.3 Feature Extraction

From the thresholding technique, the feature extraction is proceeding. The RGB color features are extracted the pre-processing step. The region filled and masked image technique is used. Region filled is used because the holes in image need to be fill. This will increase the image filter. This technique is set of by filling from edge of image that pixel cannot reached. Masked image technique is the step using the equation of multiply. The RGB image will multiply with red, green and blue band. The equation below are used to calculate masked image technique.

Masked Image Red = (Yellow component)(red band)

Masked Image Green = (Yellow component)(green band)

Masked Image Blue = (Yellow component)(blue band)

3.2.4 Making Decision

For decision making, we need to classify the image for pineapple maturity index according to its mean of pixel. From the Yellow Masked Image, mean need to calculate for entering the fuzzy making decision.

The mean red component is given as:

$$R_{mean} = \sum_{x-1}\sum_{y-1} F_{R1}(x,y)$$

$$\sum_{x-1}\sum_{y-1} F_{R2}(x,y)$$

Where:

$$F_{R1}(x,y)= \begin{cases} R(x,y) \,, R(x,y) > 0 \\ \\ 0 \quad\quad , R(x,y) = 0 \end{cases}$$

and:

$$F_{R2}(x,y)= \begin{cases} 1 \,, R(x,y) > 0 \end{cases}$$

The mean green component is given as:

$$\text{Gmean} = \sum x\text{-}1 \sum y\text{-}1 FG1(x,y) \qquad (5)$$

$$\sum x\text{-}1 \sum y\text{-}1 FG2(x,y)$$

Where:

$$F_{G1}(x,y) = \begin{cases} G(x,y) \text{ , } G(x,y) > 0 \\[1em] 1 \qquad \text{, } G(x,y) = 0 \end{cases}$$

and:

$$F_{G2}(x,y) = \begin{cases} 1 \text{ , } G(x,y) > 0 \end{cases}$$

Finally, the mean blue component is given as:

$$B_{mean} = \sum x\text{-}1 \sum y\text{-}1 F_{B1}(x,y)$$

$$\sum x\text{-}1 \sum y\text{-}1 F_{B2}(x,y)$$

Where:

$$F_{B1}(x,y) = \begin{cases} B(x,y) \text{ , } B(x,y) > 0 \\[1em] 0 \qquad \text{, } B(x,y) = 0 \end{cases}$$

and:

$$F_{B2}(x,y) = \begin{cases} 1 \text{ , } B(x,y) > 0 \\[1em] 0, B(x,y) = 0 \end{cases}$$

3.3 Fuzzy Logic

The fuzzy logic system was developed to simulate human decision making in determining maturity index of pineapple based on the color. In this process, the previous process needs to be accurate. If it is not accurate and correct, the fuzzy logic will not make the right decision to grading the maturity index for pineapples.

3.3.1 Fuzzy Rule

There are 3 input parameters are identified which is red, green and blue in this fuzzy logic systems. The mean of colors component is using to differentiate according to the maturity index given by FAMA. The blue component will remain as small due to the color of yellowish in the analysis data. This are the all the rule that construct roughly.

Red	Green	Blue
Small	Small	Small
Small	Medium	Small
Small	Large	Small
Small	Small	Medium
Small	Medium	Medium
Small	Large	Medium
Small	Small	Large
Small	Medium	Large
Small	Large	Large
Medium	Small	Small
Medium	Medium	Small
Medium	Large	Small
Medium	Small	Medium

Medium	Medium	Medium
Medium	Large	Medium
Medium	Small	Large
Medium	Medium	Large
Medium	Large	Large
Large	Small	Small
Large	Medium	Small
Large	Large	Small
Large	Small	Medium
Large	Medium	Medium
Large	Large	Medium
Large	Small	Large
Large	Medium	Large
Large	Large	Large

Table 3.11 : Fuzzy Logic roughly construct

Below is fuzzy logic rules that construct used in this research. This rule is chosen because of the suitability according to FAMA maturity index:

Red	Green	Blue	Category
Small	Large	Small	Index 2
Small	Medium	Small	Index 3
Medium	Large	Small	Index 4
Medium	Medium	Small	Index 5
Large	Medium	Small	Index 6
Large	Large	Small	Index 7

Table 3.12: Fuzzy Logic Rules

3.3.2 Membership Function

Membership functions or a fuzzy set is a major limitation in designing a fuzzy system [6]. There are many types of membership functions. In this process, the trapezoidal and triangular member ship function has been choosing. This is because the chosen membership function gives a more accurate result and it is compatible with this project using 3 parameters and 1 output.

3.3.3 Deffuzification

After execution the rules shown in previous section, the defuzzification will do the next step. Defuzzification is also known as centre of mass. In the defuzzification stage, there are methods where to making the decision from the output of membership function. There are five built-in methods supported: centroid, bisector, middle of maximum (the average of the maximum value of the output set), largest of maximum, and smallest of maximum.

Fuzzy logic will make a classification from the mean value of pineapple, and maturity has been determined. This process will calculate to get the final result. This process is 89% of pineapple correctly.

Figure 3.15: Index 1 image

Figure 3.16: Index 2 image

Figure 3.17: Index 3 image

Figure 3.18: Index 4 image

Figure 3.19: Index 5 image

Figure 3.20: Index 6 image

Figure 3.21: Index 7 image

CHAPTER 4

DEVELOPMENT SOFTWARE PROGRAM

4.1 Introduction

In this project, a software program was produced by using Image processing and Fuzzy Inference System (FIS) in MATLAB software. Therefore MATLAB software was the essential tool used throughout the whole software program development progress.
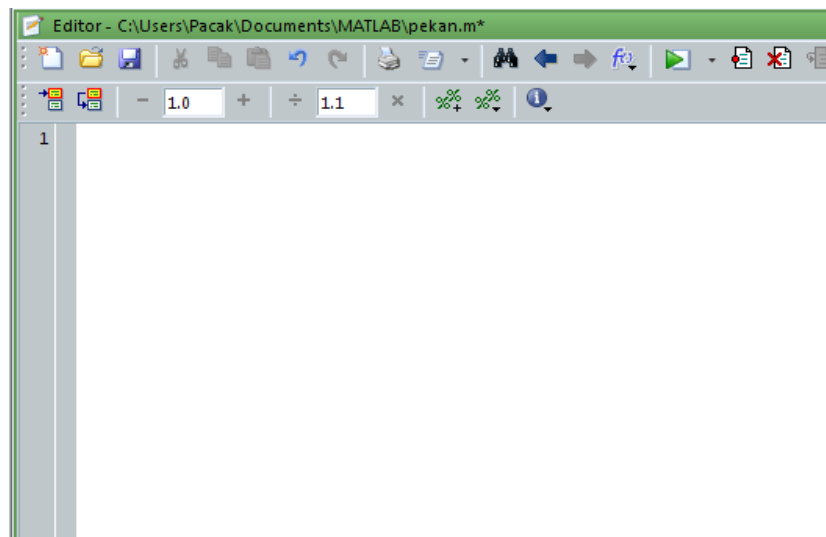
Figure 4.1 : New blank M-File

Data Collection -pineapple data of each maturity index	→	Testing Phase -Range maximum and minimum	→	Fuzzy Logic
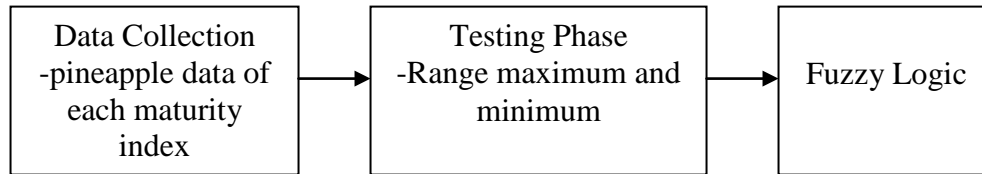
Figure 4.2 **:** Three main phases of the project
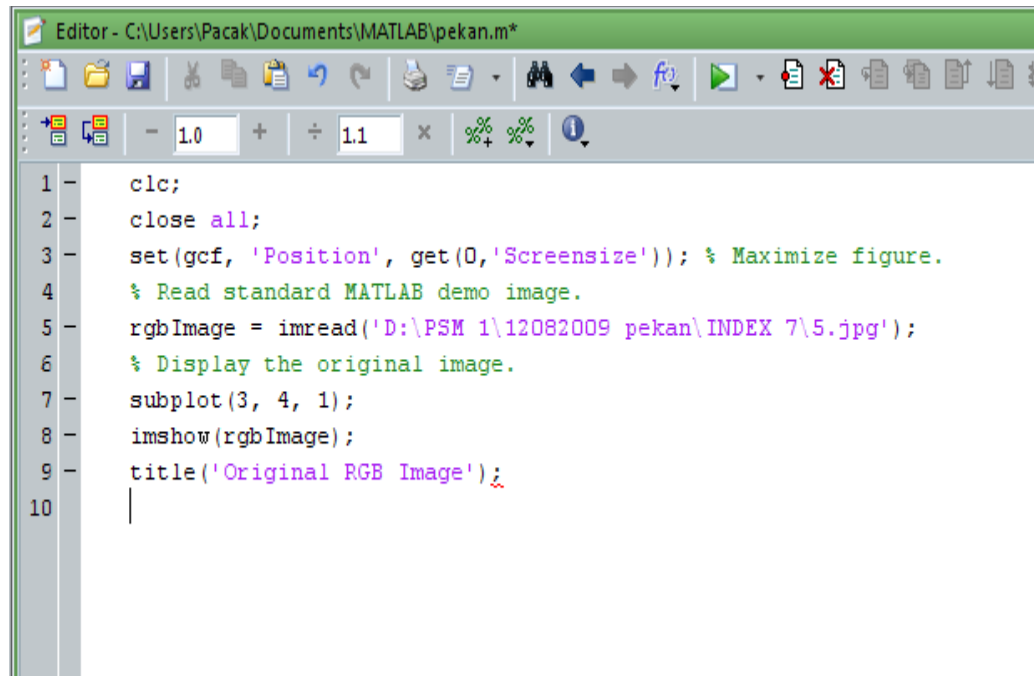
4.2 Image Processing

Data collection

To run this project, we need to load image from the database of pineapple image. The image will appear at the figure and will get maximize figure as we use 'gcf' which is current figure handle. This project need to compare a lot of image type, so the 'subplot' command is use to display all figure at once for easily to do the next technique and comparison.

The "imread" function used to import an image from any supported graphics image file format, in any of the supported bit depths. The " ('*.jpg')" is described the type of image are located at the current directory. If the other type of image is used but the directory not similar, the error of select image will appear in command window. To use several types of image, the coding need to modify within put in all of image are saved before.
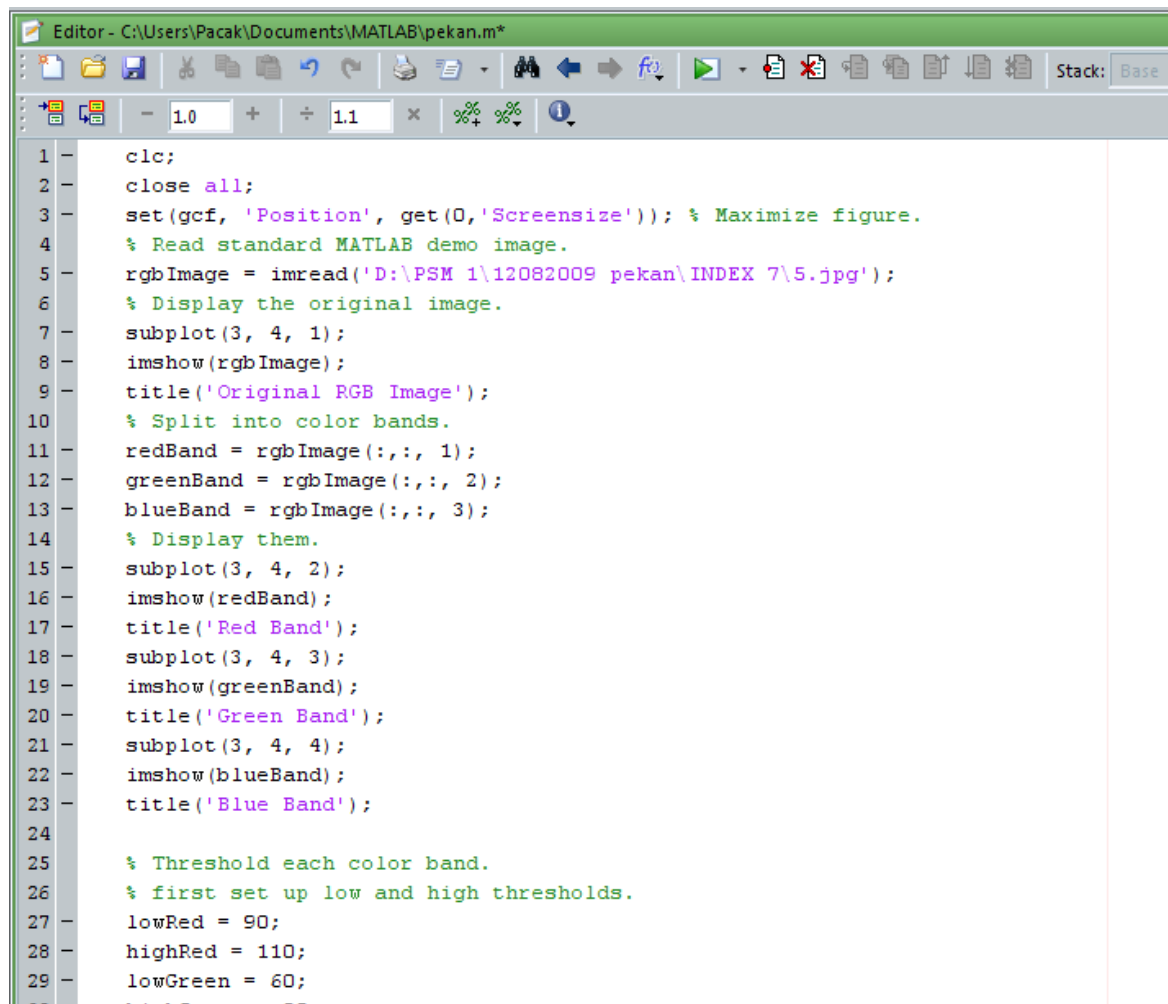
The "imshow" function displays the RGB image of the input image. The image will display as a title 'Original RGB Image'.

Figure 4.3 : Programming for show the image

```
Editor - C:\Users\Pacak\Documents\MATLAB\pekan.m*

1 -    clc;
2 -    close all;
3 -    set(gcf, 'Position', get(0,'Screensize')); % Maximize figure.
4      % Read standard MATLAB demo image.
5 -    rgbImage = imread('D:\PSM 1\12082009 pekan\INDEX 7\5.jpg');
6      % Display the original image.
7 -    subplot(3, 4, 1);
8 -    imshow(rgbImage);
9 -    title('Original RGB Image');
10     % Split into color bands.
11 -   redBand = rgbImage(:,:, 1);
12 -   greenBand = rgbImage(:,:, 2);
13 -   blueBand = rgbImage(:,:, 3);
14     % Display them.
15 -   subplot(3, 4, 2);
16 -   imshow(redBand);
17 -   title('Red Band');
18 -   subplot(3, 4, 3);
19 -   imshow(greenBand);
20 -   title('Green Band');
21 -   subplot(3, 4, 4);
22 -   imshow(blueBand);
23 -   title('Blue Band');
24
25     % Threshold each color band.
26     % first set up low and high thresholds.
27 -   lowRed = 90;
28 -   highRed = 110;
29 -   lowGreen = 60;
```

```
30    highGreen = 80;
31    lowBlue = 40;
32    highBlue = 60;
33    % Then get the binary image of where the color band
34    % falls within that threshold range.
35    redMask = (redBand > lowRed) & (redBand < highRed);
36    greenMask = (greenBand > lowGreen) & (greenBand < highGreen);
37    blueMask = (blueBand > lowBlue) & (blueBand < highBlue);
38
39    % Display them.
40    subplot(3, 4, 6);
41    imshow(redMask, []);
42    title('Red Mask');
43    subplot(3, 4, 7);
44    imshow(greenMask, []);
45    title('Green Mask');
46    subplot(3, 4, 8);
47    imshow(blueMask, []);
48    title('Blue Mask');
49    % Combine the masks to find where all 3 are "true."
50    % This will be where the "yellow" objects are.
51    yellowObjectsMask = redMask & greenMask & blueMask;
52    subplot(3, 4, 9);
53    imshow(yellowObjectsMask, []);
54    title('Combined Mask');
55    % Fill in holes, and display the image.
56    yellowObjects = uint8(imfill(yellowObjectsMask, 'holes'));
57    subplot(3, 4, 10);
58    imshow(yellowObjects, []);
59    title('Filled Mask');
60    % Multiply this mask times the original RGB image
61    % to get an image that has the red objects only.
62    maskedImageR = yellowObjects .* redBand;
63    maskedImageG = yellowObjects .* greenBand;
64    maskedImageB = yellowObjects .* blueBand;
65    maskedImage = cat(3, maskedImageR, maskedImageG, maskedImageB);
66    % Display it.
67    subplot(3, 4, 11);
68    imshow(maskedImage, []);
69    title({'Filled Mask times Original =';'Yellow Objects Only'});
70    X = mean2(maskedImage)
71    redmaskedImage = maskedImage(:,:, 1);
72    greenmaskedImage = maskedImage(:,:, 2);
73    bluemaskedImage = maskedImage(:,:, 3);
74    %calculate mean r g b
75    Xr = mean2(redmaskedImage);
76    Xg = mean2(greenmaskedImage);
77    Xb = mean2(bluemaskedImage);
```

Figure 4.4 : Programming to get the mean value of RGB

From the figure 4.4, it shown that step of development to get the mean value of from the yellowish RGB image samples. The output for this program will give result as in the result and discussion chapter.

Thresholding in RGB color space

These commands for read the pineapple data in the database.

rgbImage = imread('nenas.jpg');

For closer inspection of the RGB color space, the next block of code displays the separate color planes (red, green and blue) of an RGB image.

redBand = rgbImage(:,:, 1);
greenBand = rgbImage(:,:, 2);
blueBand = rgbImage(:,:, 3);

Figure below shows the individual RGB color bands(Red,Green,Blue) compared to the original image(*figure 4.5*):

Figure 4.5:Original Image
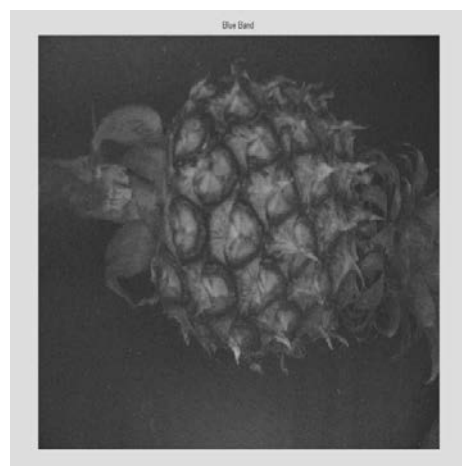

Figure 4.6:redBand

Figure 4.7:greenBand

Figure 4.8:blueBand

Command below assign the low and high thresholds for each color band:

lowRed = 90;

highRed = 110;

lowGreen = 60;

highGreen = 80;

lowBlue = 40;

highBlue = 60;

Then apply each color band threshold range to its respective color band:

redMask = (redBand > lowRed) & (redBand < highRed);

greenMask = (greenBand > lowGreen) & (greenBand < highGreen);

blueMask = (blueBand > lowBlue) & (blueBand < highBlue);

Combine the masks (Red,Green,Blue) to find where all 3 are "true." The mask of only the yellow parts of the image is shown in *Figure 4.12*.

Figure 4.9:Red Mask
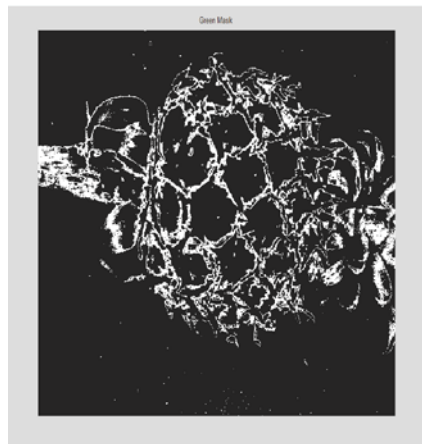
Figure 4.10:Green Mask

Figure 4.11:Blue Mask

Figure 4.12:Combined Mask

The command is shown below:

yellowObjectsMask = uint8(redMask & greenMask & blueMask);

Use the <u>unit8</u> function to convert to unsigned 8-bit integer.

I = UINT8(X) converts the elements of the array X into unsigned 8-bit integers. X can be any numeric object, such as a DOUBLE. The values of a UINT8 range from 0 to 255, or INTMIN('uint8') to INTMAX('uint8'). Values outside this range saturate on overflow, namely they are mapped to 0 or 255 if they are outside the range. If X is already an unsigned 8-bit integer array, then UINT8 has no effect. DOUBLE and SINGLE values are rounded to the nearest UINT8 value on conversion.

Regions Filled

Fill in any holes in the regions, since they are most likely yellow also. Use the <u>imfill</u> function as shown below:

yellowObjectsMask = uint8(imfill(yellowObjectsMask, 'holes'));

`BW2 = imfill(BW,'holes')` fills holes in the binary image `BW`.A hole is a set of background pixels that cannot be reached by filling in the background from the edge of the image. *Figure 4.13* show the image after fills the holes.
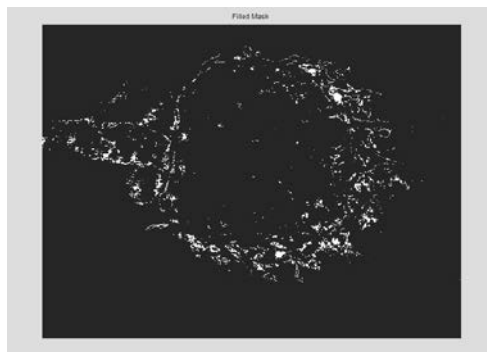

Figure 4.13:Filled Mask

Masked Original Image

Convert the type of yellowObjectsMask to the same data type as hImage. Use the <u>cast</u> function:

yellowObjectsMask = cast(yellowObjectsMask, class(rgbImage));

`B = cast(A, newclass)` converts `A` to class `newclass`, where `newclass` is the name of a built-in data type compatible with `A`. The `cast` function truncates any values in `A` that are too large to map into `newclass`.

Use the yellow object mask to mask out the yellow-only portions of the rgb image.

maskedImageR = yellowObjects . redBand;*
maskedImageG = yellowObjects . greenBand;*
maskedImageB = yellowObjects . blueBand;*

Figure below show the three types of masked image which is the masked red image (*figure 4.14*), masked green image (*figure 4.15*) and masked blue image (*figure 4.16*).
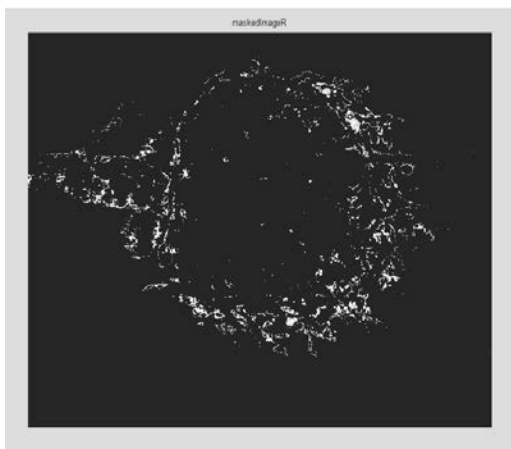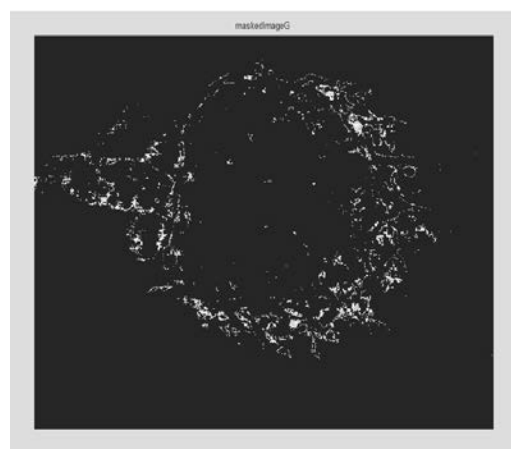

Figure 4.14:Masked Red Image
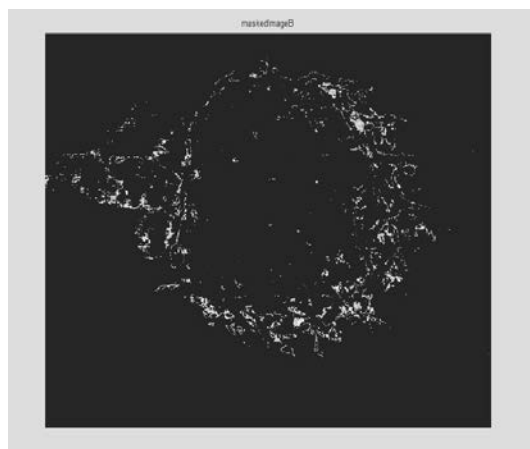

Figure 4.15:Masked Green Image

Figure 4.16:Masked Blue Image

Concatenate the masked color bands to form the RGB image by using the <u>cat</u> function:

maskedImage = cat(3, maskedImageR, maskedImageG, maskedImageB);

CAT(DIM,A,B) concatenates the arrays A and B along the dimension DIM. CAT(2,A,B) is the same as [A,B]. CAT(1,A,B) is the same as [A;B]. B = CAT(DIM,A1,A2,A3,A4,...) concatenates the input arrays A1, A2, etc. along the dimension DIM.

4.3 Fuzzy Logic

4.3.1 Introduction To Fuzzy Logic Toolbox

Fuzzy Logic Toolbox is a problem-solving control system methodology that lends itself to implementation in system ranging from simple, small, embedded micro controllers to large, networked, multichannel PC or workstation-based and control the systems. It is ideally suited for dealing with these types of uncertainty which means to do a decision of classifies the maturity index. These systems can be created by using graphical tool.

Fuzzy Inferences System (FIS)

The most important thing for build Fuzzy Inferences System (FIS) is the rules and membership must be right. In this fuzzy logic system, 3 input and 1 output has been used.

Mean value of RGB color are the input for fuzzy logic and the output are maturity index from index 2 until index 7. The table 5.1 until table 5.6 in chapter 5 will show the mean value of each index.

i. Structure of Fuzzy Inferences System

The next figure will shown the set of red, green and blue set for fuzzy logic. This is constructing due to the maximum and minimum of mean each color from the previous process.
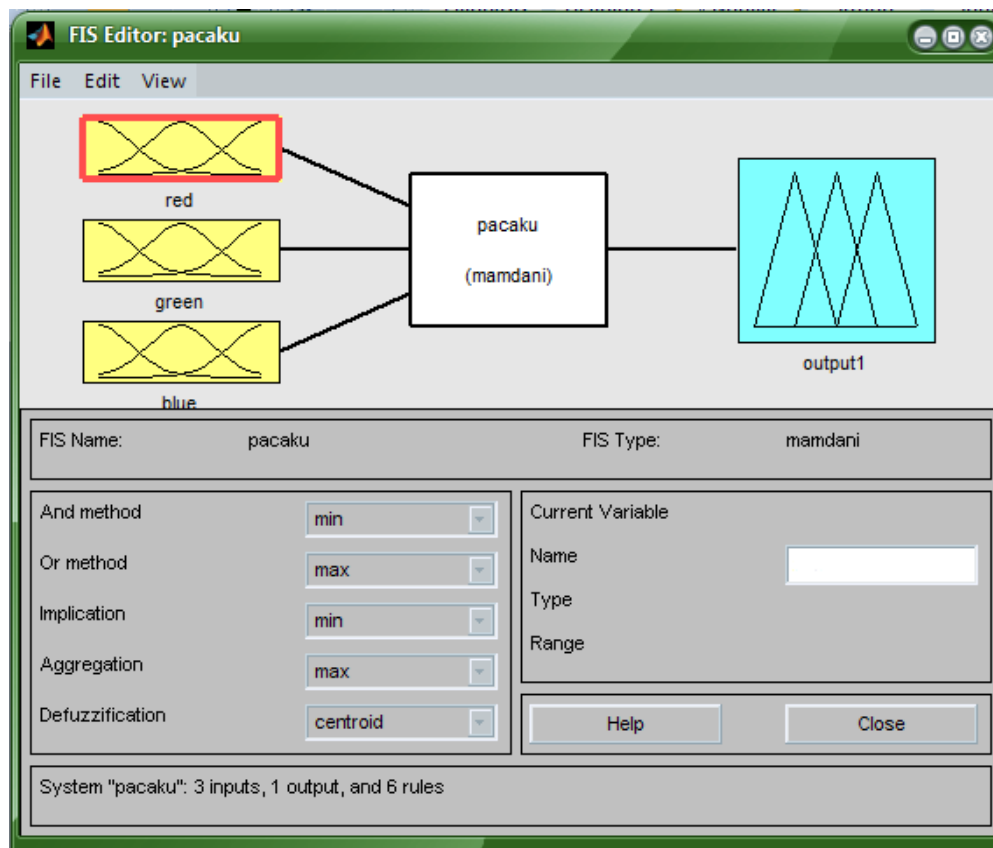

Figure 4.17 : FIS Editor

ii. Define the Membership Functions

The misclassification is mostly due to design of the membership function and fuzzy rules that are based on experienced and knowledge [10]. Decision for the right shape and boundary for membership function will lead to the increasing accuracy of fuzzy system. The first step is to take the inputs and determine the degree to which they belong to each of the appropriate fuzzy sets via membership

functions. In this project the input are red, green and blue with range 0 to 1 and the output is category with range also from 0 to 1. This range is referring to the mean value of image after the feature extraction.

In this system, the trapezoidal and triangle membership function are chosen. This decision are decided due to some testing in the system. Figure 4.18, 4.19, 4.20, 4.21 shown the membership function that has been chosen.
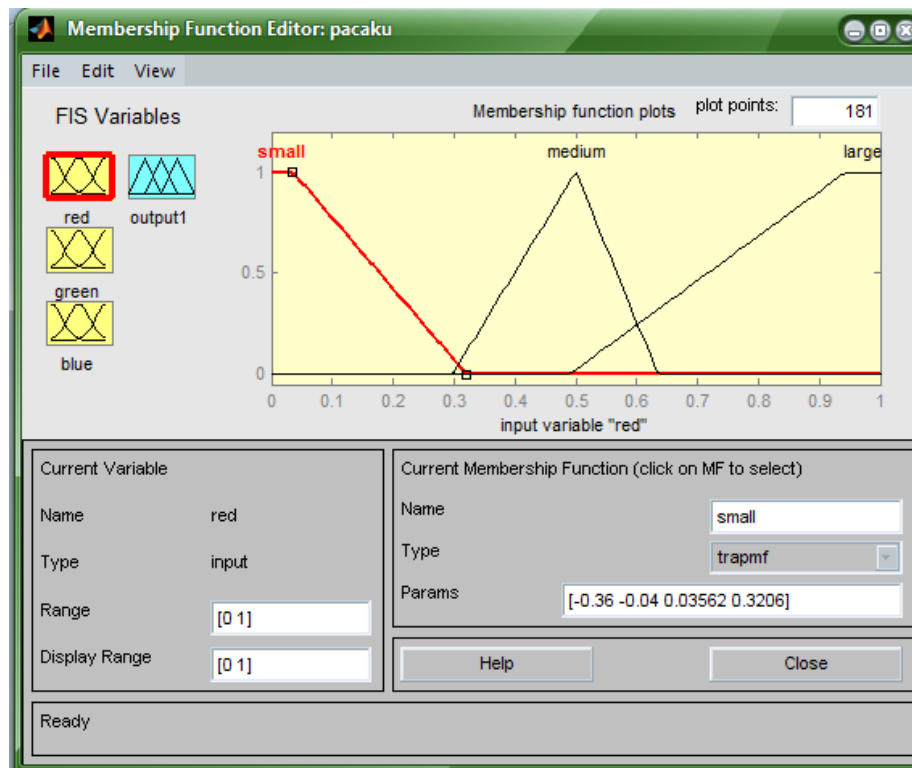

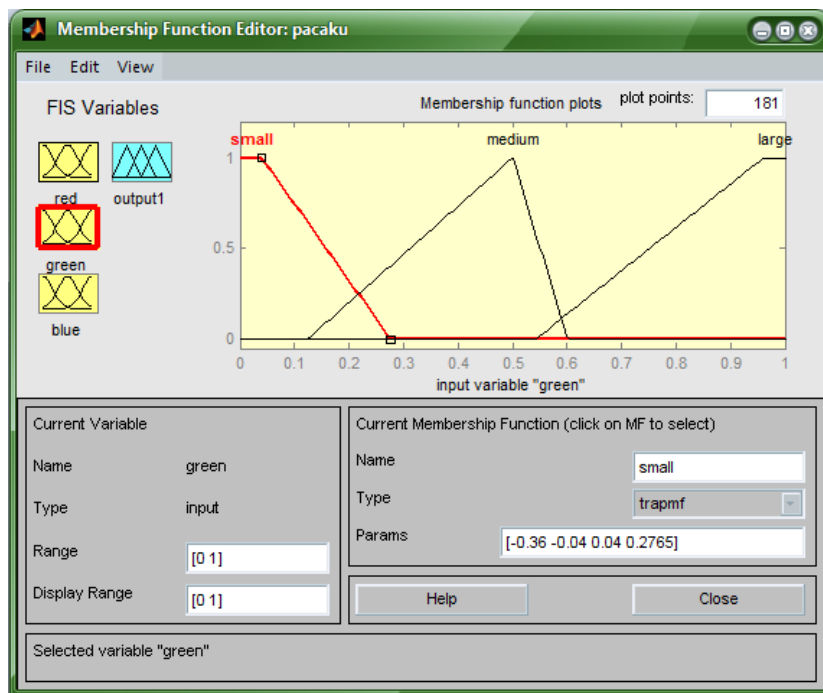Figure 4.18 : Membership Function for input Red

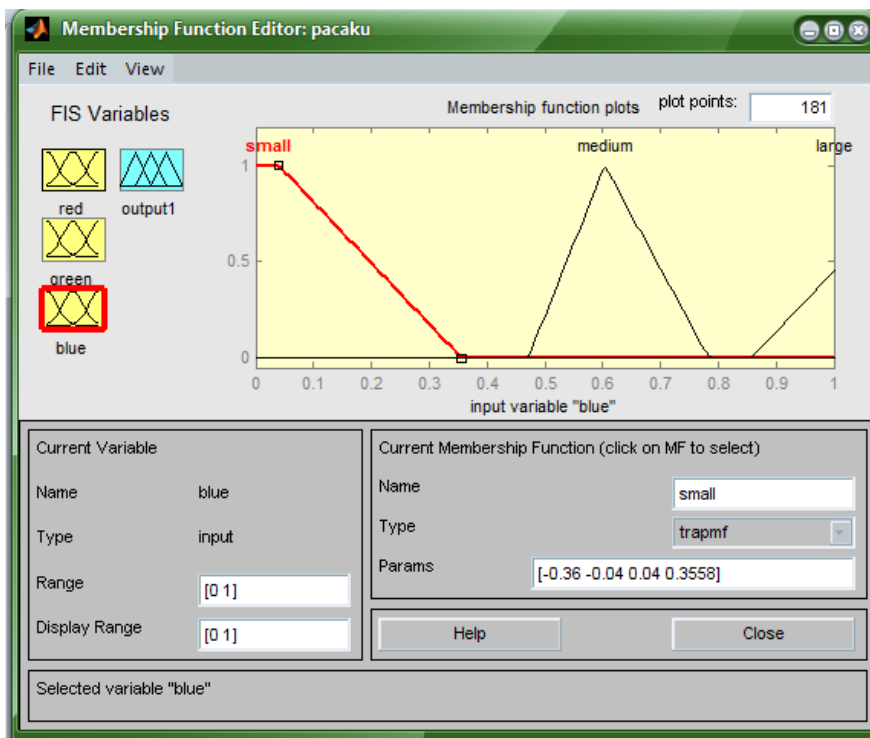Figure 4.19 : Membership Function for input Green
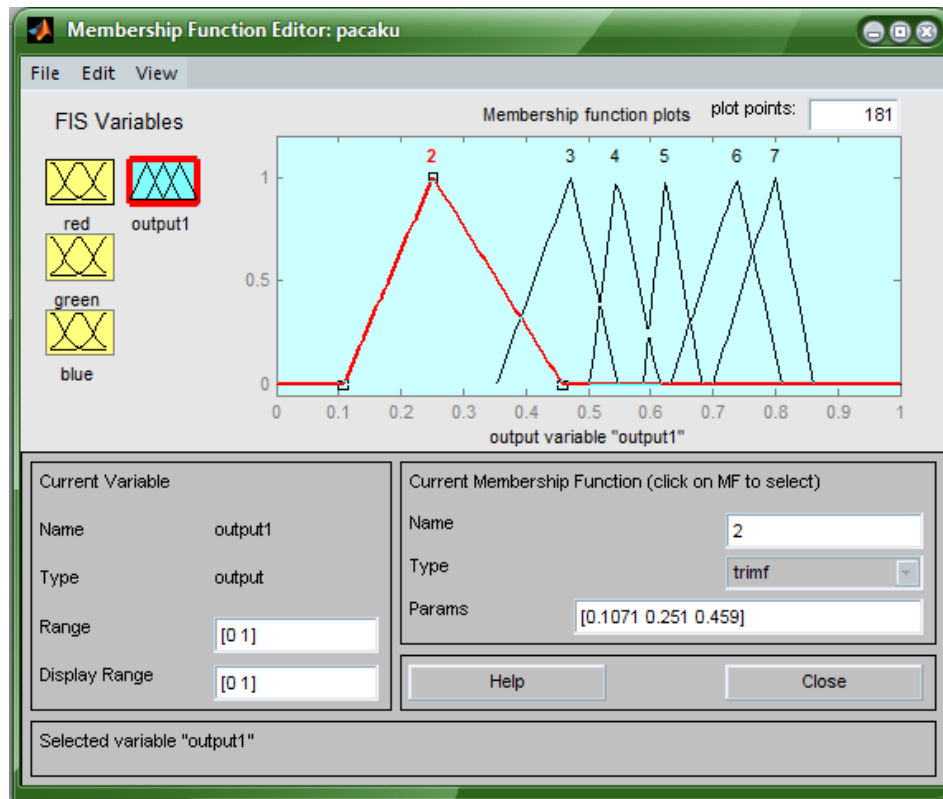

Figure 4.20 : Membership Function for input Blue

Figure 4.21 : Membership Function for output

iii. Construct IF-THEN Rules

Fuzzy rules are the main character to using the fuzzy system more correctly. The rules need to be done more careful. If it is not accurate and correct, the fuzzy logic will not make the right decision to grading the maturity index for pineapples. Figure 4.22 had shown the rule that has made for this fuzzy logic system.
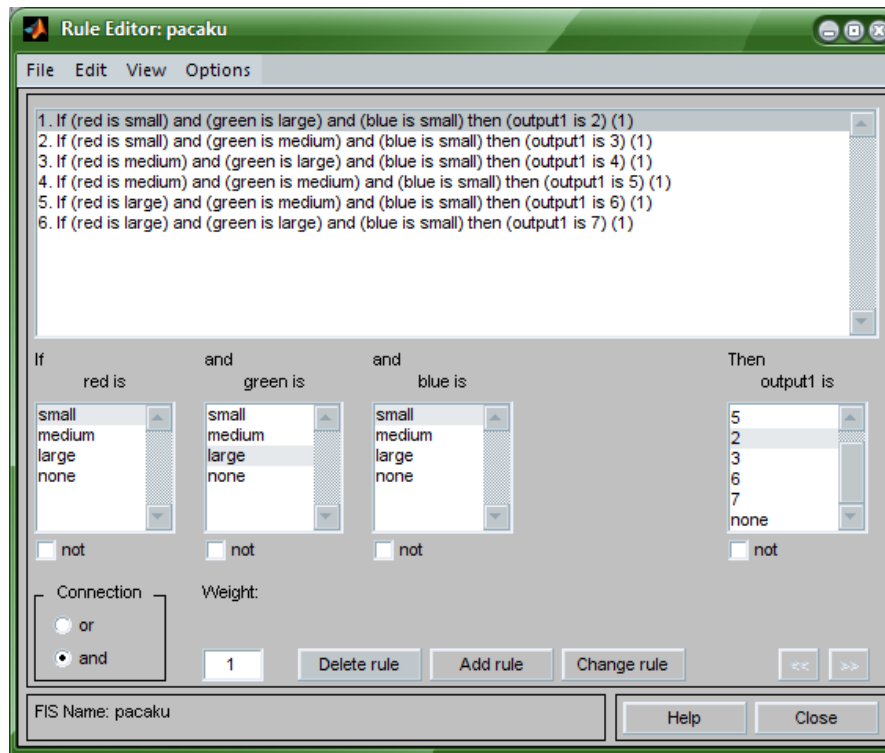
Figure 4.22: IF-THEN Rules

iv.   Visualize and Deploy the Fuzzy Inference Diagram

Rule from the previous need to do test for decision making. These rule is really important because if the rule is not correct, the decision will not be precise. Aggregation technique is the process that represents the output of each rule combined in single set of fuzzy according to combination of fuzzy sets. Figure 4.23 shown that defuzzication of the systems for index 7 maturity level.
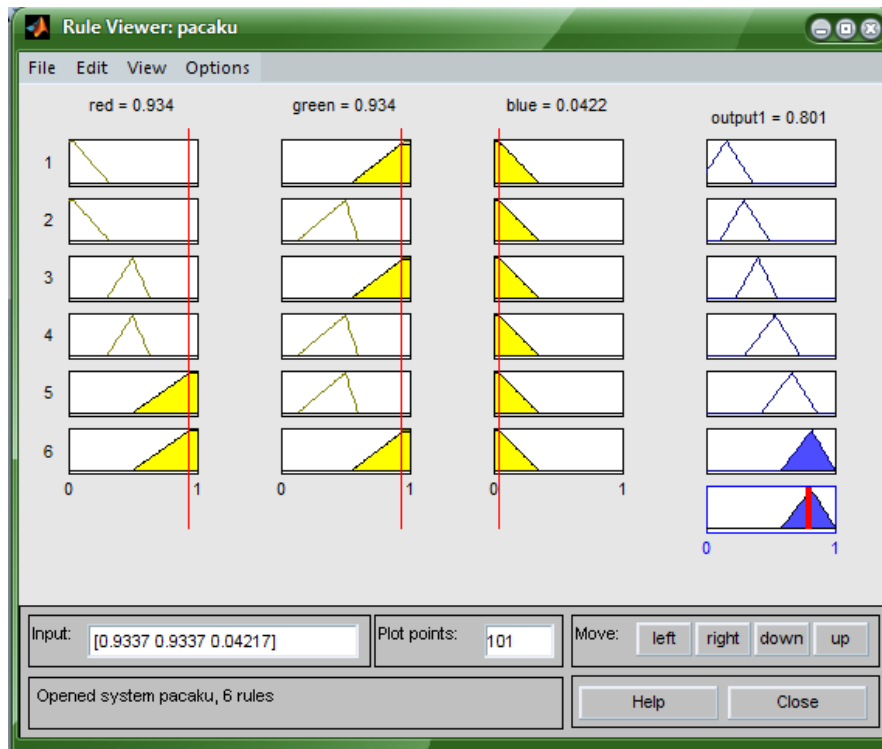
Figure 4.23: Result for six rules that obtained from Rule Viewer

CHAPTER 5

RESULT AND DISCUSSION

5.1 The analysis of Results

The programming from MATLAB has calculated the mean color intensity to find maturity index for pineapple. This method is done by 30 pictures for samples, where there represents 5 samples for maturity indexes. From this mean value, we can separate the maturity index according to the mean value from yellowish images. The mean RGB for each maturity indexes is shown in table 5,6,7,8,9 and 10.

Mean of RGB			
Samples	Red	Green	Blue
1	0.3220	0.2310	0.1724
2	0.1530	0.1092	0.0832
3	0.1205	0.0843	0.0676
4	0.1162	0.0803	0.0647
5	0.1577	0.1141	0.0855

Table 5.1: Mean RGB Intensity of the sample for index 2

Mean of RGB			
Samples	Red	Green	Blue
1	0.3080	0.2293	0.1616
2	0.3254	0.2419	0.1741
3	0.4100	0.2973	0.2142
4	0.2984	0.2158	0.1603
5	0.3050	0.2240	0.1675

Table 5.2: Mean RGB Intensity of the sample for index 3

Mean of RGB			
Samples	Red	Green	Blue
1	0.3300	0.2318	0.1822
2	0.3387	0.2322	0.1834
3	0.3484	0.2501	0.1844
4	0.4696	0.3230	0.2524
5	0.4023	0.2865	0.2031

Table 5.3 : Mean RGB Intensity of the sample for index 4

Mean of RGB			
Samples	Red	Green	Blue
1	0.4467	0.3086	0.2370
2	0.2975	0.1872	0.1440
3	0.5285	0.3649	0.2785
4	0.6349	0.4425	0.3276
5	0.4347	0.2986	0.2277

Table 5.4 : Mean RGB Intensity of the sample for index 5

Mean of RGB			
Samples	Red	Green	Blue
1	0.4323	0.2878	0.2217
2	0.6002	0.4076	0.3065
3	0.6634	0.4520	0.3387
4	0.7167	0.5017	0.3449
5	0.8718	0.6191	0.4420

Table 5.5 : Mean RGB Intensity of the sample for index 6

Mean of RGB			
Samples	Red	Green	Blue
1	0.5189	0.3536	0.2645
2	0.7736	0.5014	0.3434
3	0.6555	0.4458	0.3372
4	0.7205	0.4928	0.3705
5	0.6899	0.4634	0.3546

Table 5.6 : Mean RGB Intensity of the sample for index 7

This is the line chart for each maturity index using the mean from the calculation that have been obtain in the previous process.
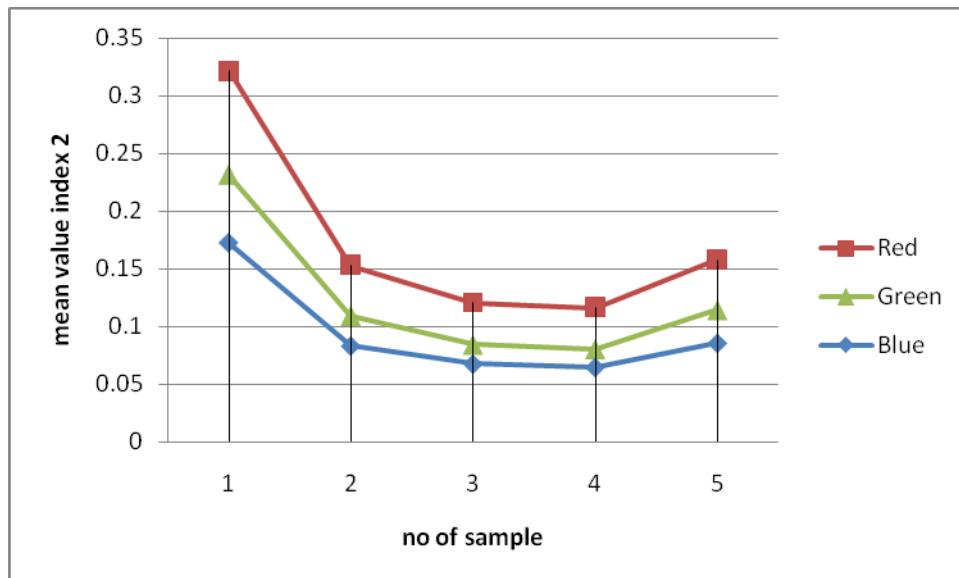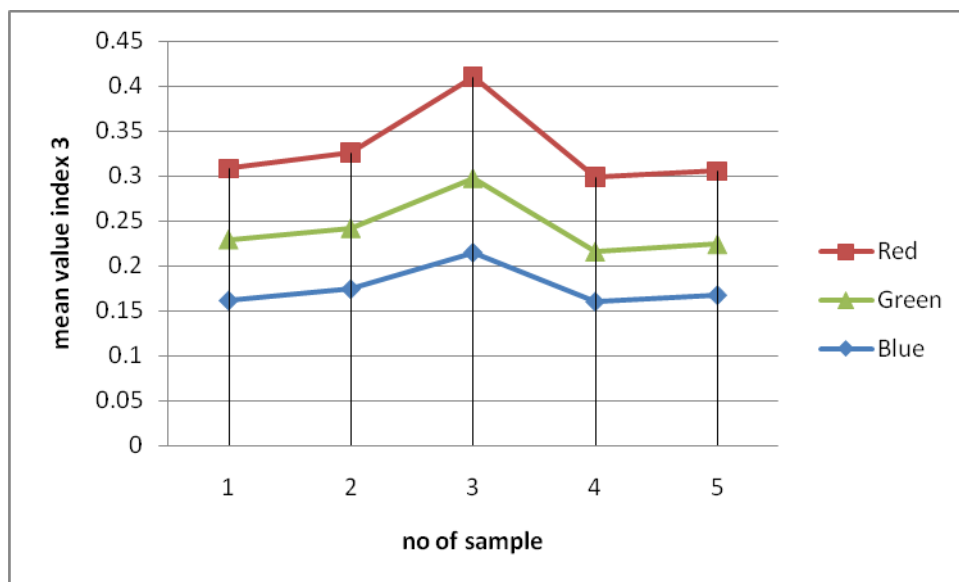
Figure 5.1: line chart for index 2

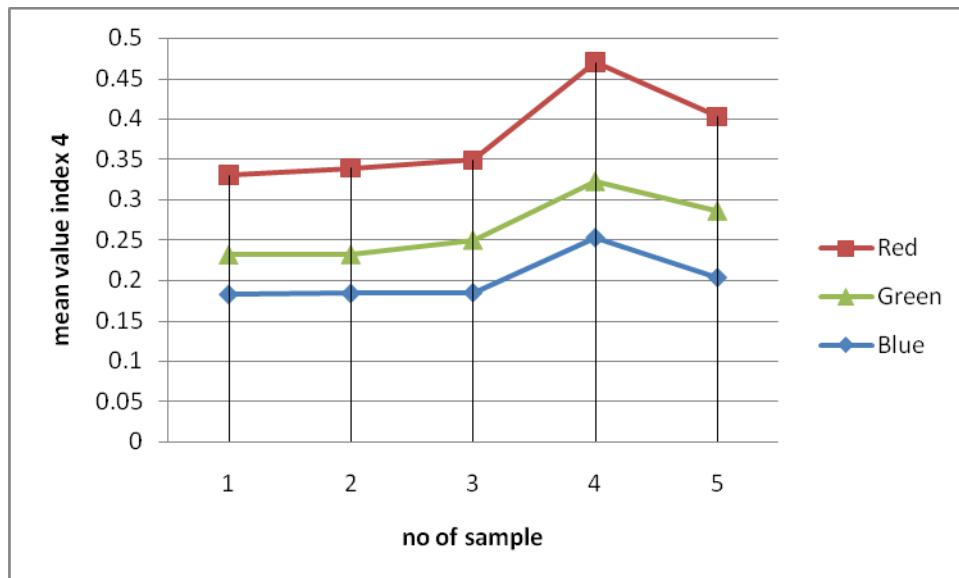Figure 5.2: line chart for index 3

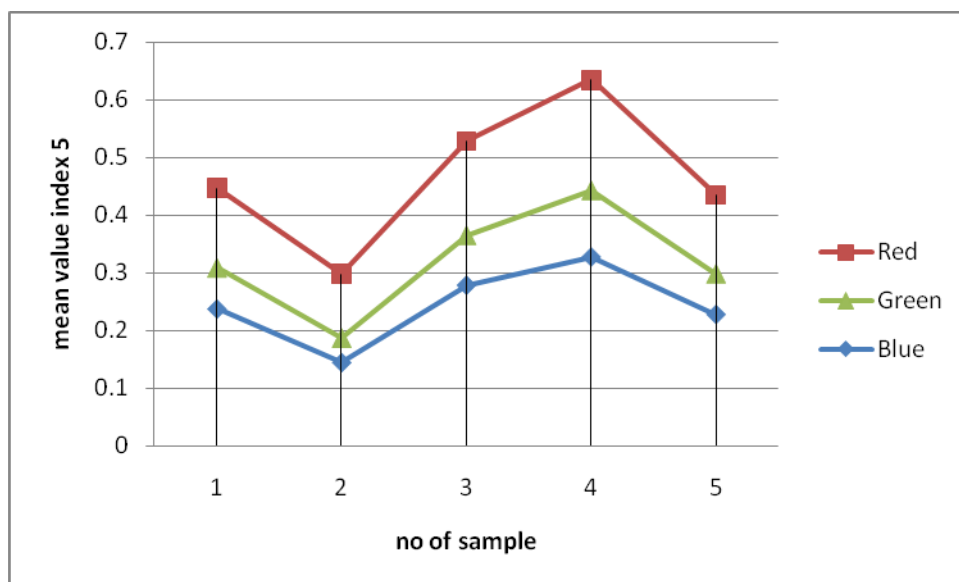Figure 5.3: line chart for index 4
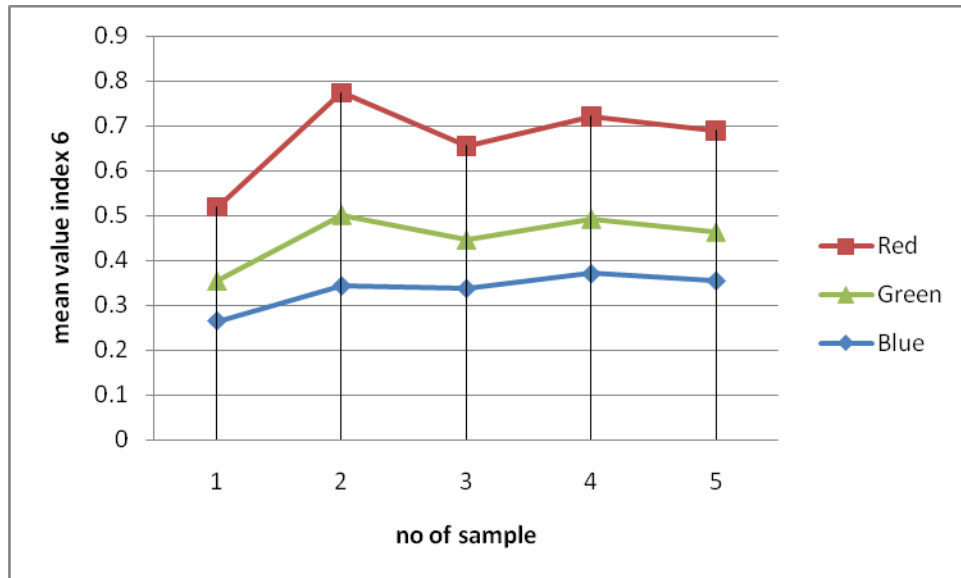

Figure 5.4: line chart for index 5
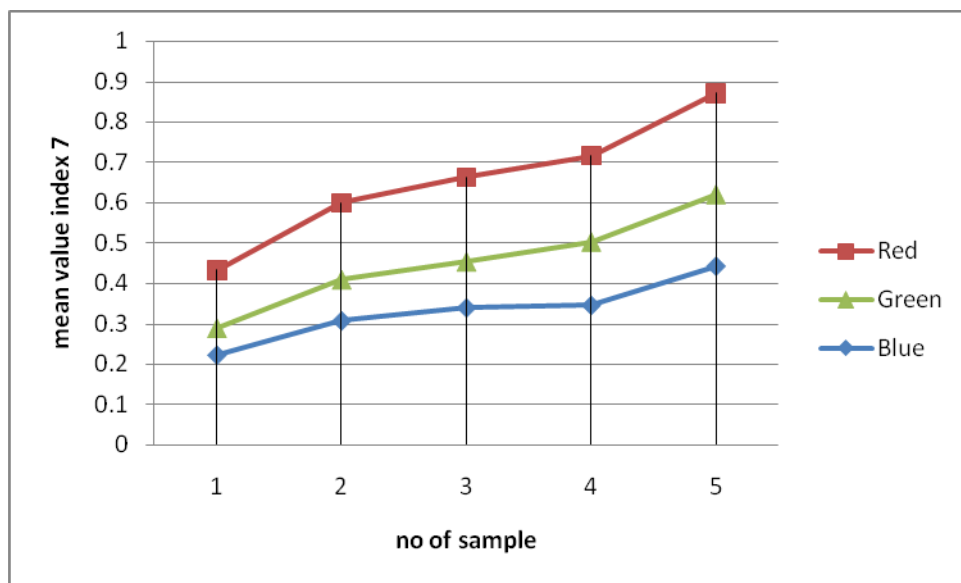
Figure 5.5: line chart for index 6

Figure 5.6: line chart for index 7

The figure 5.1, 5.2, 5.3, 5.4, 5.5, 5.6 clearly show that red and green is dominant color for every maturity index. Meanwhile the blue color is noise and they are not required. Two of the mean color component (red and green) are identified as the input parameters to the fuzzy system while the mean blue component was ignored for analysis since it insignificant in each level of maturity index applied. It is because the yellow color can be obtained as pixel value red = 255, green = 255, and blue = 0.

Figure 5.7 until figure 5.12 shown that the final result after feature extraction. This result is an output after using the thresholding and masking technique. The extraction of the image will give a result of yellowish in the pineapple. Yellowish of the pineapple represent the level of the maturity level.
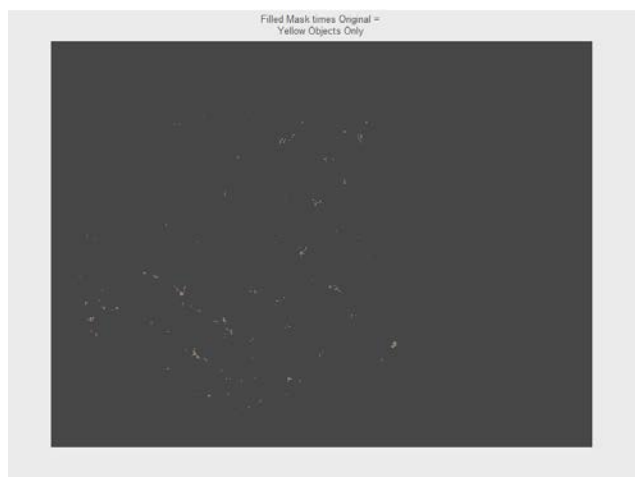
Index 2

Figure 5.7 : final result feature extraction for index 2

Index 3

Figure 5.8 : final result feature extraction for index 3
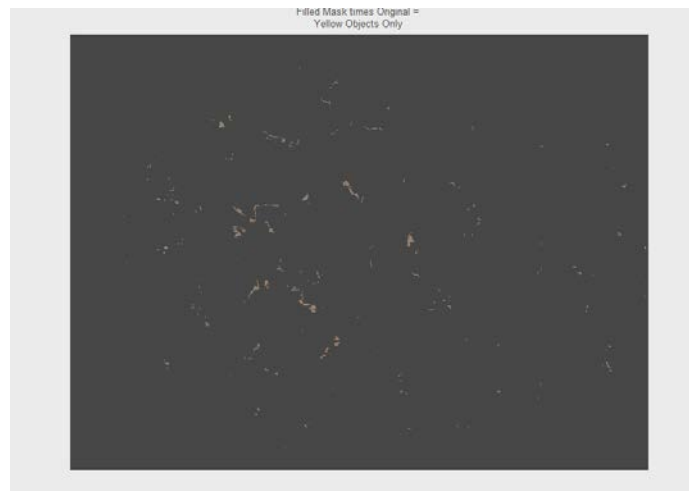
Index 4

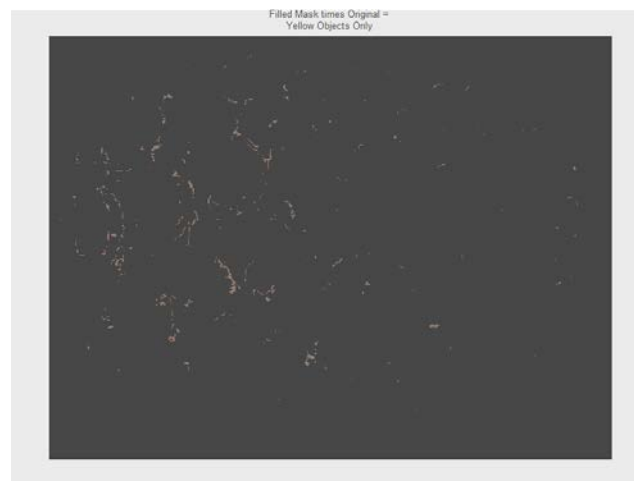Figure 5.9 : final result feature extraction for index 4

Index 5

Figure 5.10 : final result feature extraction for index 5
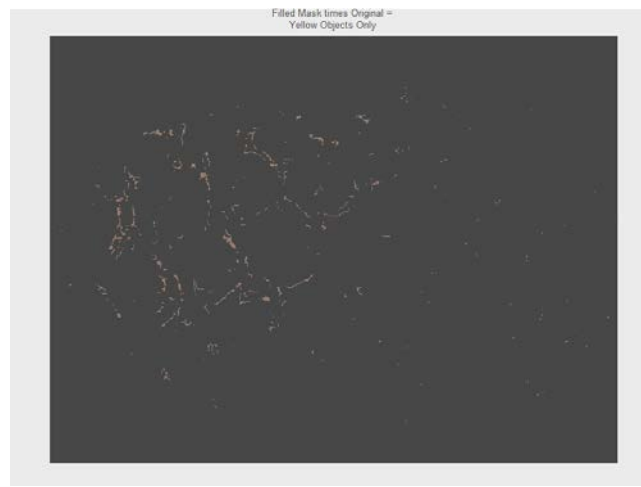
Index 6

Figure 5.11 : final result feature extraction for index 6
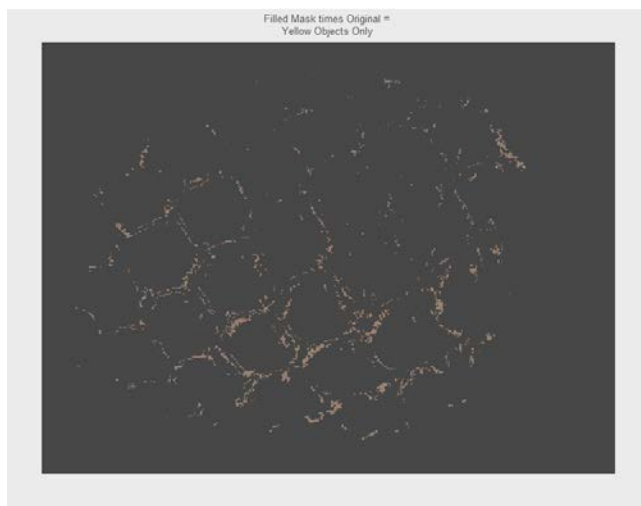
Index 7

Figure 5.12 : final result feature extraction for index 7

Figure 5.7 shown that it is rounded overall dark green with some yellowish between the eyes at the base. This characteristic according to the Federal Agricultural Marketing Authority (FAMA), it is a index 2. The yellowish in the index is increasing until index 7. Show figure 5.9 that is index 4 is 25% of the pineapple is orange yellowish. This percentage is increasing 50% for index 5 in figure 5.10 and 75% for index 6 in figure 5.11. In figure 5.12 that the image of pineapple eyes is whole orange yellowish which means it is ripen and it is not suitable for market selling.

This yellowish extraction is really needed for the future process because need to calculate the mean of each data red, green and blue for this image. The process of decision making will do by fuzzy logic system because it is more precise and accurate.

5.2. Fuzzy Logic Decision

Fuzzy Logic is the best decision making system. This technique is more accurate because it is using human languages as making the decision. Grading results obtained from Fuzzy Logic showed 89% general agreement with the results from the human expert, providing good flexibility in reflecting the expert's expectations and grading standards into the results. Figure 5.13, 5.14 and 5.15 below shown the result from the rule viewer.
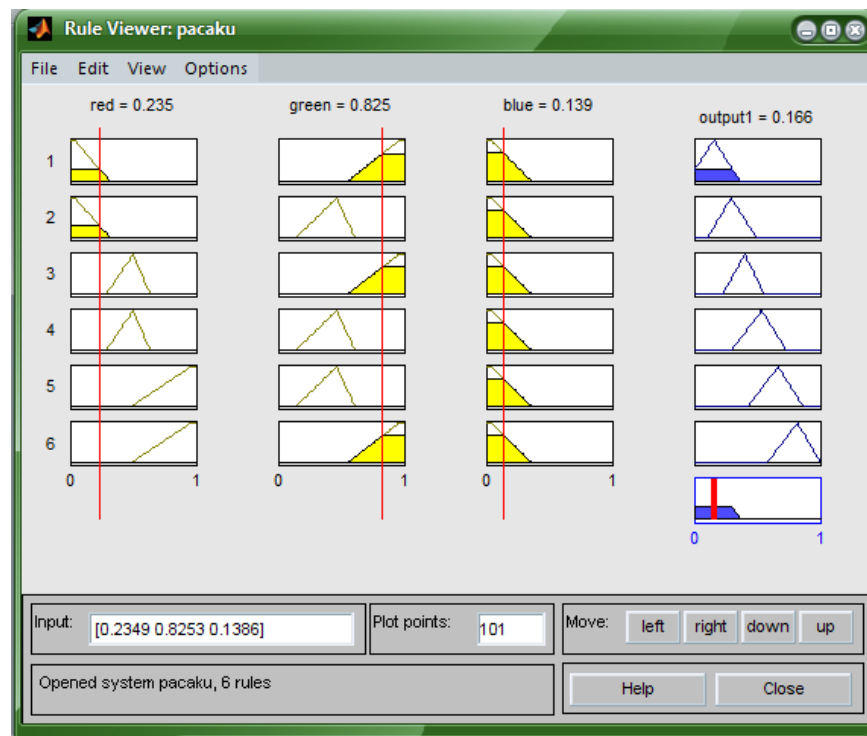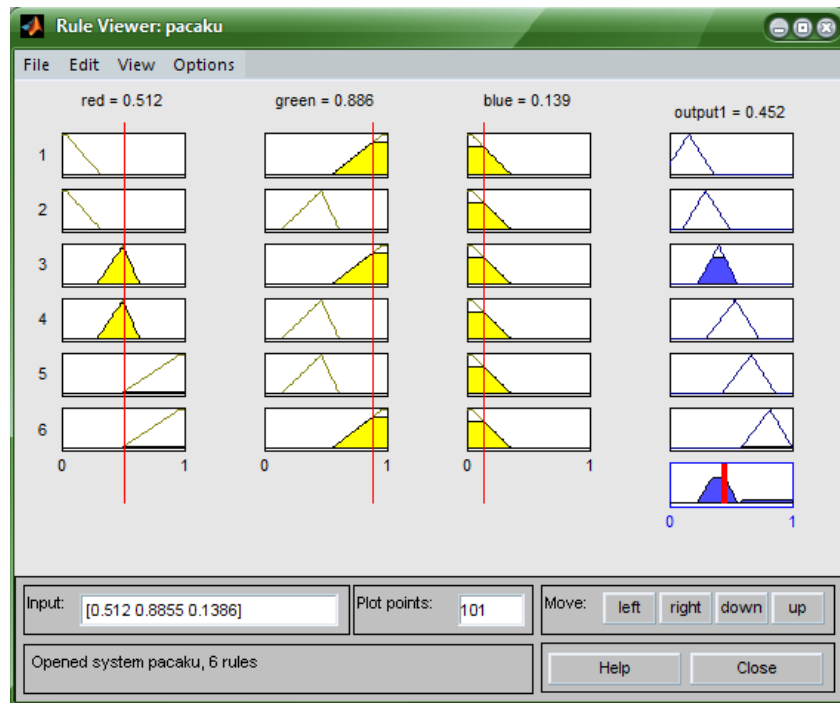

Figure 5.13: Index 2 defuzzification

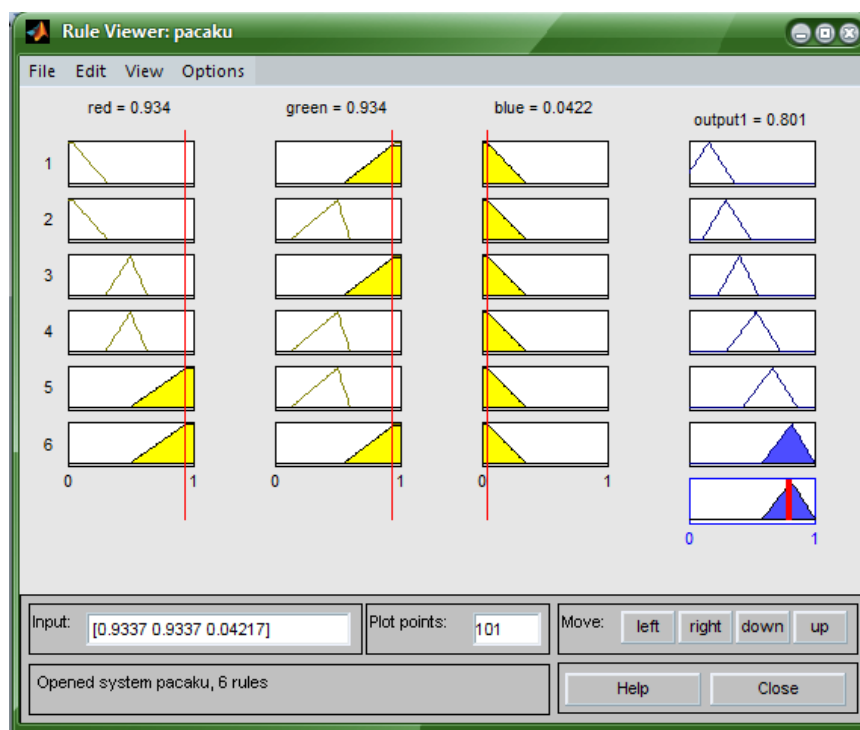Figure 5.14 : Index 4 defuzzification

Figure 5.15 : Index 7 defuzzification

Figure 5.14 and 5.15 shows that the defuzzification for index 2 and index 7. The output for maturity range in fuzzy sets is:

If output1 is 0.1075<value<0.459, it is index 2

If output1 is 0.353<value<0.5482, it is index 3

If output1 is 0.5013<value<0.614, it is index 4

If output1 is 0.589<value<0.681, it is index 5

If output1 is 0.6317<value<0.8107, it is index 6

If output1 is 0.7<value<0.8611, it is index 7

This fuzzy output is suitable for classify the maturity index of pineapple. The output gives 89% accuracy due to the testing value result. The membership function input which is red, green and blue has been analyze using the testing mean value. The table 5.7 shows the analysis for each index and membership function.

Index	accuracy, %				
	trapmf	gaussmf	trimf	dsigmf	sigmf
Index 2	95	70	82	69	38
Index 3	95	73	79	63	35
Index 4	94	62	77	65	28
Index 5	89	60	75	60	20
Index 6	79	69	77	67	25
Index 7	83	67	79	65	21

Table 5.7 : Accuracy for choosing input membership function

CHAPTER 6

CONCLUSION AND RECOMMENDATION

6.1   Conclusion

The inspection using identification of pineapple maturity index successfully more than 89% accuracy. Color based identification was chosen and decision making was done by fuzzy logic systems. Yellowish of the pineapple is the main features for this identification. Threshold and masking technique was implemented to increase accuracy. The accuracy also has been amplified by decision in fuzzy system.

Finally, the complete project via a Fuzzy Inference System (FIS) built with the MATLAB Toolbox. The FIS is seemed easier to develop but need more studied to understand each set tool of function in this software. For FIS, the rule is much more important for proceed the decision.

6.2 Future Development

In the future, there are a few things that can be fixed or added in order to improve this system such as lighting system and images capture device(camera).

6.2.1 Lighting

Vision systems are affected by the level and quality of lighting as with the human eye. The performance of the lighting system greatly influences the quality of image and play an important role in the overall efficiency and accuracy of the system. The light focuses on the materials. Lighting type, location and color quality play an important role in bringing out a clear image of the object. Front lighting focusing on the object for better detection of the surface features of the product while back-lighting is used for enhancing the background of the product. Light sources used include incandescent lamps, fluorescent lamps, lasers, X-ray tubes and infra-red lamps. A typical lighting set for image processing is as shown in *figure (5.1)*.
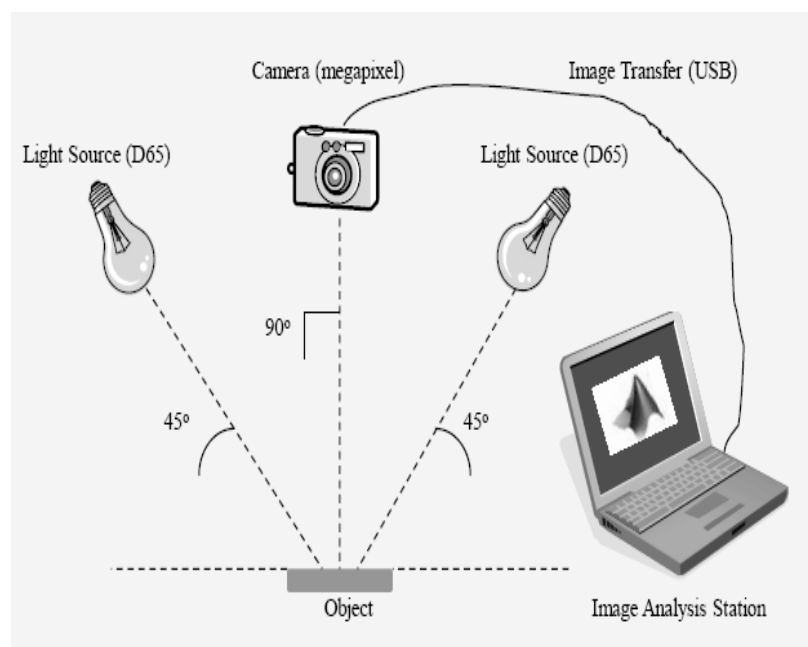
Figure 6.1: Lighting

6.2.2   Image Capture Device

Image capturing devices that can be used in this project are the solid state charged coupled device (CCD) camera. Images captured or taken by digital camera maintain the features of the images with little noise due to its variable resolution. A charge coupled device (CCD) camera is an apparatus which is designed to convert optical brightness into electrical amplitude signals using a plurality of CCDs, and then reproduce the image of a subject using the electric signals without time restriction.

Charge coupled devices or CCDs are arrays of semiconductor gates formed on a substrate of an integrated circuit or chip. The gates of the CCD are operative to individually collect, store and transfer charge. When used in image applications, the charge collected and stored in each gate of the array represents a picture element or pixel of an image. The CCD image sensor includes an image sensing section, which performs photoelectric conversion, and a storage section, which is arranged separate from the image sensing section and temporarily stores charges acquired by the photoelectric conversion. Charge coupled device (CCD) camera systems are configured to capture signals according to many different CCD output formats and pixel configurations.

6.3   Costing and Commercialization

This project only requires of software and the small material of hardware is digital camera. The license of Matrix Laboratory (MATLAB) is required to activate this software.   However, there is free trial version on MATLAB available as an alternative for the user.

The project is in a development process where there is still some part or elements that need to be added to the project. If the project is complete until the matching process and has its own real time pineapple scanner, it can be implement in many field such as for agricultural industry and pineapple exportation.

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[9]   Farah Yasmin Abdul Rahman, Shah Rizam Mohd Shah Baki, Ahmad Ihsan Mohd Yassin, Nooritawati Md. Tahir and Wan Illia Wan Ishak (2009), IEEE, Monitoring of Watermelon Ripeness Based on Fuzzy Logic

[10] Zadeh, L.A. 1965. Fuzzy sets. Information and Control, 8: 338-353.

APPENDIX A

Program Listing

```
clc;

close all;

set(gcf, 'Position', get(0,'Screensize')); % Maximize figure.

% Read standard MATLAB demo image.

rgbImage = imread('D:\PSM 1\simpang renggam\index 2\11.jpg');

% Display the original image.

% subplot(3, 4, 1);

% imshow(rgbImage);

% title('Original RGB Image');

% Split into color bands.

redBand = rgbImage(:,:, 1);

greenBand = rgbImage(:,:, 2);

blueBand = rgbImage(:,:, 3);

% Display them.

% subplot(3, 4, 2);

% imshow(redBand);

% title('Red Band');

% subplot(3, 4, 3);

% imshow(greenBand);

% title('Green Band');

% subplot(3, 4, 4);

% imshow(blueBand);

% title('Blue Band');

%

% % Threshold each color band.

% % first set up low and high thresholds.

lowRed = 90;

highRed = 110;

lowGreen = 60;

highGreen = 80;
```
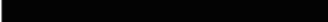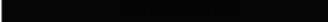
```
lowBlue = 40;
highBlue = 60;
% % Then get the binary image of where the color band
% % falls within that threshold range.
redMask = (redBand > lowRed) & (redBand < highRed);
greenMask = (greenBand > lowGreen) & (greenBand < highGreen);
blueMask = (blueBand > lowBlue) & (blueBand < highBlue);
%
% % Display them.
% subplot(3, 4, 6);
% imshow(redMask, []);
% title('Red Mask');
% subplot(3, 4, 7);
% imshow(greenMask, []);
% title('Green Mask');
% subplot(3, 4, 8);
% imshow(blueMask, []);
% title('Blue Mask');
% Combine the masks to find where all 3 are "true."
% This will be where the "yellow" objects are.
yellowObjectsMask = redMask & greenMask & blueMask;
% subplot(3, 4, 9);
% imshow(yellowObjectsMask, []);
% title('Combined Mask');
% Fill in holes, and display the image.
yellowObjects = uint8(imfill(yellowObjectsMask, 'holes'));
% subplot(3, 4, 10);
% imshow(yellowObjects, []);
% title('Filled Mask');
% Multiply this mask times the original RGB image
% to get an image that has the red objects only.
```

```
maskedImageR = yellowObjects .* redBand;

maskedImageG = yellowObjects .* greenBand;

maskedImageB = yellowObjects .* blueBand;

maskedImage = cat(3, maskedImageR, maskedImageG, maskedImageB);

% Display it.

% subplot(3, 4, 11);

imshow(maskedImage, []);

title({'Filled Mask times Original =';'Yellow Objects Only'});

X = mean2(maskedImage)

redmaskedImage = maskedImage(:,:, 1);

greenmaskedImage = maskedImage(:,:, 2);

bluemaskedImage = maskedImage(:,:, 3);

%calculate mean r g b

Xr = mean2(redmaskedImage);

Xg = mean2(greenmaskedImage);

Xb = mean2(bluemaskedImage);
```

APPENDIX B

RGB color Mapping

Shades of Black and Gray (see also Gray vs Grey)

Color Name	Credits	R;G;B Dec	RGB Hex	CSS Hex	BG/FG color sample
Grey	N	84;84;84	545454		
Grey, Silver	V	192;192;192	C0C0C0		
grey	X	190;190;190	BEBEBE		
LightGray	X	211;211;211	D3D3D3		
LightSlateGrey	X	119;136;153	778899	789	
SlateGray	X	112;128;144	708090		
SlateGray1	X	198;226;255	C6E2FF		
SlateGray2	X	185;211;238	B9D3EE		
SlateGray3	X	159;182;205	9FB6CD		
SlateGray4	X	108;123;139	6C7B8B		
black	N,V,X	0;0;0	000000	000	
grey0	X	0;0;0	000000	000	
grey1	X	3;3;3	030303		
grey2	X	5;5;5	050505		
grey3	X	8;8;8	080808		
grey4	X	10;10;10	0A0A0A		
grey5	X	13;13;13	0D0D0D		
grey6	X	15;15;15	0F0F0F		
grey7	X	18;18;18	121212		

coral	N	255;127;0	FF7F00		
coral	X	255;127;80	FF7F50		
coral1	X	255;114;86	FF7256		
coral2	X	238;106;80	EE6A50		
coral3	X	205;91;69	CD5B45		
coral4	X	139;62;47	8B3E2F		
honeydew	X	240;255;240	F0FFF0		
honeydew1	X	240;255;240	F0FFF0		
honeydew2	X	224;238;224	E0EEE0		
honeydew3	X	193;205;193	C1CDC1		
honeydew4	X	131;139;131	838B83		
orange	X	255;165;0	FFA500		
orange1	X	255;165;0	FFA500		
orange2	X	238;154;0	EE9A00		
orange3	X	205;133;0	CD8500		
orange4	X	139;90;0	8B5A00		
salmon	X	250;128;114	FA8072		
salmon1	X	255;140;105	FF8C69		
salmon2	X	238;130;98	EE8262		
salmon3	X	205;112;84	CD7054		
sienna	X	160;82;45	A0522D		
sienna1	X	255;130;71	FF8247		
sienna2	X	238;121;66	EE7942		
sienna3	X	205;104;57	CD6839		
sienna4	X	139;71;38	8B4726		
Mandarian Orange	N	142;35;35	8E2323		
Orange	N	255;127;0	FF7F00		
Orange Red	N	255;36;0	FF2400		
DeepPink	X	255;20;147	FF1493		
DeepPink1	X	255;20;147	FF1493		
DeepPink2	X	238;18;137	EE1289		
DeepPink3	X	205;16;118	CD1076		
DeepPink4	X	139;10;80	8B0A50		
HotPink	X	255;105;180	FF69B4		
LightPink	X	255;182;193	FFB6C1		
LightPink1	X	255;174;185	FFAEB9		
LightPink2	X	238;162;173	EEA2AD		
LightPink3	X	205;140;149	CD8C95		
LightPink4	X	139;95;101	8B5F65		
MediumVioletRed	X	199;21;133	C71585		
MistyRose	X	255;228;225	FFE4E1		
MistyRose1	X	255;228;225	FFE4E1		
MistyRose2	X	238;213;210	EED5D2		
MistyRose3	X	205;183;181	CDB7B5		
MistyRose4	X	139;125;123	8B7D7B		
OrangeRed	X	255;69;0	FF4500		
OrangeRed1	X	255;69;0	FF4500		
OrangeRed2	X	238;64;0	EE4000		
red	N,V,X	255;0;0	FF0000	f00	
red1	X	255;0;0	FF0000	f00	
red2	X	238;0;0	EE0000	e00	
red3	X	205;0;0	CD0000		
red4	X	139;0;0	8B0000		
tomato	X	255;99;71	FF6347		
tomato1	X	255;99;71	FF6347		
tomato2	X	238;92;66	EE5C42		
tomato3	X	205;79;57	CD4F39		
tomato4	X	139;54;38	8B3626		
Dusty Rose	N	133;99;99	856363		
Firebrick	N	142;35;35	8E2323		
Indian Red	N	245;204;176	F5CCB0		
MediumPurple1	X	171;130;255	AB82FF		
Dark Orchid	N	153;50;205	9932CD		
MediumPurple2	X	159;121;238	9F79EE		
MediumPurple3	X	137;104;205	8968CD		
MediumPurple4	X	93;71;139	5D478B		

AliceBlue	X	240;248;255	F0F8FF		
BlueViolet	X	138;43;226	8A2BE2		
Cadet Blue	N	95;159;159	5F9F9F		
CadetBlue	X	95;158;160	5F9EA0		
CadetBlue	X	95;158;160	5F9EA0		
CadetBlue1	X	152;245;255	98F5FF		
CadetBlue2	X	142;229;238	8EE5EE		
CadetBlue3	X	122;197;205	7AC5CD		
CadetBlue4	X	83;134;139	53868B		
Corn Flower Blue	N	66;66;111	42426F		
CornflowerBlue	X	100;149;237	6495ED		
DarkSlateBlue	X	72;61;139	483D8B		
DarkTurquoise	X	0;206;209	00CED1		
DeepSkyBlue	X	0;191;255	00BFFF		
DeepSkyBlue1	X	0;191;255	00BFFF		
DeepSkyBlue2	X	0;178;238	00B2EE		
DeepSkyBlue3	X	0;154;205	009ACD		
DeepSkyBlue4	X	0;104;139	00688B		
DodgerBlue	X	30;144;255	1E90FF		
DodgerBlue1	X	30;144;255	1E90FF		
DodgerBlue2	X	28;134;238	1C86EE		
LightBlue	X	173;216;230	ADD8E6		
LightBlue1	X	191;239;255	BFEFFF		
LightBlue2	X	178;223;238	B2DFEE		
LightBlue3	X	154;192;205	9AC0CD		
LightBlue4	X	104;131;139	68838B		
LightCyan	X	224;255;255	E0FFFF		
LightCyan1	X	224;255;255	E0FFFF		
LightCyan2	X	209;238;238	D1EEEE		
LightCyan3	X	180;205;205	B4CDCD		
LightCyan4	X	122;139;139	7A8B8B		
LightSkyBlue	X	135;206;250	87CEFA		
LightSkyBlue1	X	176;226;255	B0E2FF		
LightSkyBlue2	X	164;211;238	A4D3EE		
LightSkyBlue3	X	141;182;205	8DB6CD		
LightSkyBlue4	X	96;123;139	607B8B		
LightSlateBlue	X	132;112;255	8470FF		
		153;204;255	99CCFF	9cf	
LightSteelBlue	X	176;196;222	B0C4DE		
aquamarine	X	127;255;212	7FFFD4		
blue	N,V,X	0;0;255	0000FF	00f	
blue1	X	0;0;255	0000FF	00f	
blue2	X	0;0;238	0000EE	00e	
blue3	X	0;0;205	0000CD		
blue4	X	0;0;139	00008B		
aqua	V	0;255;255	00FFFF	0ff	
cyan	N,X	0;255;255	00FFFF	0ff	

APPENDIX C

Fuzzy Demo

trimf

trapmf
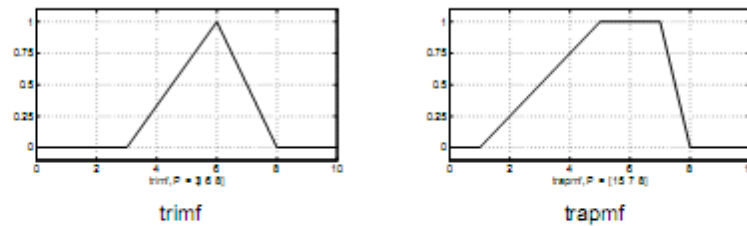
Two membership functions are built on the *Gaussian* distribution curve: a simple Gaussian curve and a two-sided composite of two different Gaussian curves. The two functions are gaussmf and gauss2mf.

The *generalized bell* membership function is specified by three parameters and has the function name gbellmf. The bell membership function has one more parameter than the Gaussian membership function, so it can approach a non-fuzzy set if the free parameter is tuned. Because of their smoothness and concise notation, Gaussian and bell membership functions are popular methods for specifying fuzzy sets. Both of these curves have the advantage of being smooth and nonzero at all points.

gaussmf

gauss2mf

gbellmf
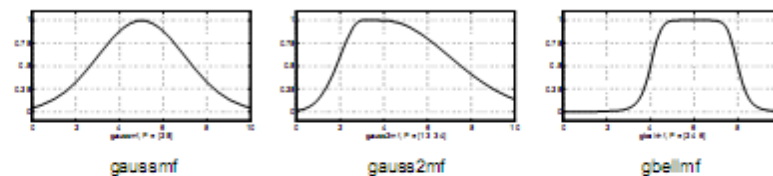
Although the Gaussian membership functions and bell membership functions achieve smoothness, they are unable to specify asymmetric membership functions, which are important in certain applications. Next, you define the *sigmoidal* membership function, which is either open left or right. Asymmetric and closed (i.e. not open to the left or right) membership functions can be synthesized using two sigmoidal functions, so in addition to the basic sigmf, you also have the difference between two sigmoidal functions, dsigmf, and the product of two sigmoidal functions psigmf.

| sigmf | dsigmf | psigmf |
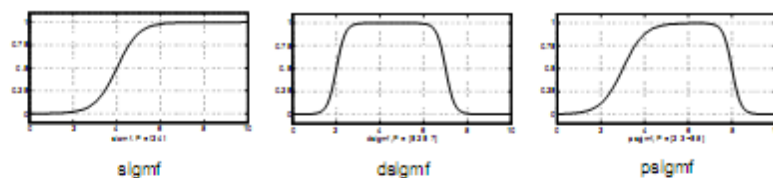
Polynomial based curves account for several of the membership functions in the toolbox. Three related membership functions are the *Z*, *S*, and *Pi curves*, all named because of their shape. The function zmf is the asymmetrical polynomial curve open to the left, smf is the mirror-image function that opens to the right, and pimf is zero on both extremes with a rise in the middle.

| zmf | pimf | smf |
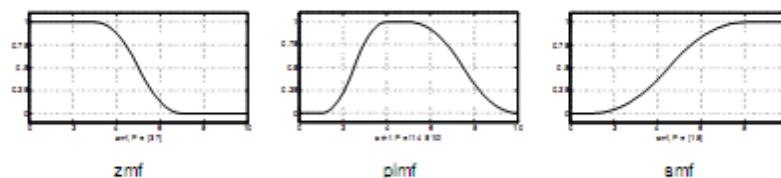
There is a very wide selection to choose from when you're selecting a membership function. You can also create your own membership functions with the toolbox. However, if a list based on expanded membership functions seems too complicated, just remember that you could probably get along very well with just one or two types of membership functions, for example the triangle and trapezoid functions. The selection is wide for those who want to explore the possibilities, but expansive membership functions are not necessary for good fuzzy inference systems. Finally, remember that more details are available on all these functions in the reference section.