DETERMINATION OF RIPENESS OF PALM FRUITS (FFB)

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Degree of Master of Science

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This dissertation submitted in partial fulfillment of therequirements for the Degree Master of Science in Computer Science

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DECLARATION

I declare that this is my own work and this dissertation does not incorporate without acknowledgement any material previously submitted for a Degree or Diploma in any other University or institute of higher learning and to the best of my knowledge and belief it does not contain any material previously published or written by another person except where the acknowledgement is made in the text.

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Supervisor:

The above candidate has carried out research for the Masters thesis under my supervision.

....

Dr. Chathura De Silva Date

ABSTRACT

Demand for palm oil is increasing rapidly. Ripeness of the Fresh Fruit Bunches (FFB) plays a vital role in determining the quality of the CPO and oil content in the fruits. Therefore FFBs should be placed under suitable category for processing of oil in the mills. Categorizing the palm bunches according to their ripeness is the most critical step of the mill grading process. A common method of determining the ripeness of palm fruit is by visual inspection of the palm bunches by experienced individuals for which the colour of the fruit and amount of lose fruits become the main attribute. Changes of colour indicate the stages of ripeness. Categorizing the palm fruit bunches according to their ripeness by manual inspection is tedious, inconsistent, time consuming and inaccurate. This research focuses on a solution to the palm oil industry for this problem, based on image processing which will increase the quality of the oil and speed up the grading process, by the result of automating the mill grading process. The solution focuses on categorizing the palm bunches into three groups namely; under-ripped, ripped and over-ripped.

ACKNOWLEDGEMENTS

It is a pleasure to express my deepest thanks to my project supervisor, Dr. Chathura De Silva, for his priceless guiding and support given by sharing his knowledge, research materials, advices, supervision and useful suggestions throughout this research work. His expertise and continuous guidance enabled me to complete my work successfully.

I am grateful for the support, guidance and advice given throughout by my co-supervisor Dr. Indika Perera.

I would like to express my sincere gratitude to my husband, parents and family for their love and support throughout my life and support given to complete my MSc. Finally, I wish to express my gratitude to all my colleagues at Goodhope, for the support given to me to manage and complete my research work successfully.

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LIST OF ABBREVIATIONS

ANN	–	Artificial Neural Network
DN	–	Digital Numbers
FFB	–	Fresh Fruit Bunches
GUI	–	Graphical User Interface
NIR	–	Near Infra-Red
PCA	–	Principal Component Analysis
CPO	–	Crude Palm Oil
Ha	–	Hectare
MATLAB	–	Matrix Laboratory
MPOB	–	Malaysian Palm Oil Board

CHAPTER 1

INTRODUCTION

Global production of and demand for palm oil is increasing rapidly. Plantations are spreading across Asia, Africa and Latin America [14]. Palm tree produces high-quality oil that is used primarily for cooking in developing countries. It is also used in food products, detergents, cosmetics and bio-fuel.183.65 million Tons of edible palm oils and fats are consumed annually [15].

Currently bunch counters go to the plantation and manually check if the bunches are ready for harvesting based on the loose fruits on the ground and colour of the surface of the fruit. Based on the condition of the fruit, quality of the oil differs. For the bunch to be of superior quality 90% of the bunch should have ripened; 80% should have been ripened for the bunch to be of good quality and 70% should have been ripened for the bunch to be of general quality [6]. After the palm bunches are harvested, they are brought to the loading ramp for mill grading. The bunches are categorized manually into rat damaged bunches, ripped bunches, under ripped bunches, over ripped bunches and dirty bunches. This has to be done very fast as the fruits cannot be kept for long after they are harvested. The longer they are kept, the more fatty acids will be generated which will reduce the quality of the crude palm oil [13]. Fatty acid content in palm bunches should be less than 5% for the production of good quality Crude Palm Oil (CPO). Manual grading method is tedious and may be inaccurate. By observing the tender fruit bunches manual prediction is done to estimate the harvest yield after a certain time period.

This research focuses on automating the mill grading process and proposes a system for the palm industry, based on image processing techniques for palm industry to categorize the palm bunches for mill grading which would increase the quality of the oil by reducing the fatty oil generated in fruits by speeding up the grading process.

Goodhope Asia Holdings has about 40,000 Ha of matured palm trees and 160,000 Ha of palm trees expected to mature in 2020. As an employee of Goodhope Asia Holdings, I propose this system for faster mill grading process for Goodhope Asia Holdings.

1.1 Classification of Palm Bunches

Malaysian Palm Oil Board (MPOB) has established fifteen classes of FFB in the grading of oil palm in palm oil mills: ripe, underripe, unripe, overripe, empty, rotten, long stalk, unfresh/old, dirty, small, pest damaged, diseased, dura, loose fruit, and wet [9]. The colour changes during these stages are from black to orange [2].

This research study focuses on three categories; ripped bunches, under ripped bunches, and over ripped bunches.

- Ripe bunch

Figure 1: Ripe bunch

Ripe bunches have reddish outer layer and its mesocarp are yellow coloured. This bunch has at least ten (10) loose sockets and more than fifty percent (50%) of the fruits are attached to the bunch. There should be 10-15% of loose fruits in a bunch, for the fruit to be categorized under the "ripe category", according to MPOB standards.

- Unripe bunch

Figure 2: Unripe bunch

Unripe Bunch is black or purple-black and outer layer of fruit mesocarp is yellowish. These bunches have no fresh fruit socket during inspection at the refinery. Fruit socket on unripe bunch is not caused by the usual process of maturity. There should be 1-9% of loose fruits in a bunch, for the fruit to be categorized under the “ripe category”, according to MPOB standards.

- Over ripe bunch

Figure 3: Over ripe bunch

Over Ripe Bunch are bunches of fresh fruit with dark red and more than fifty (50%) fruits detached, but at least ten percent (10%) still attached to the fresh fruit bunches during the inspection at the factory.

- Under ripe bunches

Figure 4: Under ripe bunches

Under Ripe Bunch is orange in colour and reddish or reddish-purple and outer layer of fruit mesocarp is yellowish orange coloured. These bunches have less than ten (10) loose sockets during inspection at the refinery.

- Dirty bunch

Figure 5: Dirty bunch

Dirty bunch are bunches with more than half of its surface with muddy, sandy, and mixed with stones or other impurities.

- Empty bunch

Figure 6: Empty bunch

Empty Fruit Bunch is a bunch which is more than ninety percent (90%) fruits detached from the bunch.

1.2 Research Problem

The main research problem that this research study is trying to address is the manual mill grading process. Metric Tons of palm bunches are brought to the loading bay daily and they are graded by decisions based on human grader's vision. Human mill grading process is time consuming and the possibility of human error during inspection is high. It is subject to disputes among the mill graders.

Not separating of riped and over-riped FFB will affect the quality of the oil.

Mill grading can be done only by persons having experience in grading. Bunches need to be graded as fast as possible because the longer they are kept, the more fatty acids will be generated which will reduce the quality of the crude palm oil.

Colour is one of the main indicators of ripeness and it provides information to determine the ripeness and the maturity of the fruits. Therefore colour becomes an important factor in determining the grade and the quality of the palm oil.

According to a research that was conducted by Federal Land Development Authority, Malaysia in 2012 the estimated oil content for ripe palm bunches is 60%; underripe is 40% and unripe is 20% [26]. Ripe fruits are selected to assure the maximum level of oil quality.

1.3 Objectives

- To automate the manual vision based mill grading process.
- To reduce the maintenance cost of the machineries.
- To increase the oil quality by the proper categorization of palm bunches; because non separation of ripe and overripe bunches will cause oil quality to be effected and it will result in negative impact on health.
- To avoid disputes among human graders and sellers

CHAPTER 2

LITERATURE REVIEW

2.1 Colour detection

Colour is an important feature in determining the ripeness of FFBs. Colour detection is a part of image processing that involves differentiation between objects based on their colour. Colours are detected by analyzing three beams of reflected colored light (red, blue, green), then measuring the level of light reflected back on each wave length. It is a process of segmenting the colours and identifying the segmented colours. Colour provides information such as maturity and freshness of fruits in the bunch. [10] RGB is not the best colour space to work in as RGB will vary with illuminations. In case of fruits where a curved surface is, the RGB values will change with the angle the fruit surface normal makes with the optical axis of the camera/light source.

2.2 Image segmentation

Image segmentation is the process of dividing an image into multiple parts[8]. This is typically used to identify objects or other relevant information in digital images. In palm FFB images there are two distinct regions; spikes and fruits. For this research study the fruits region is the focused area of interest.

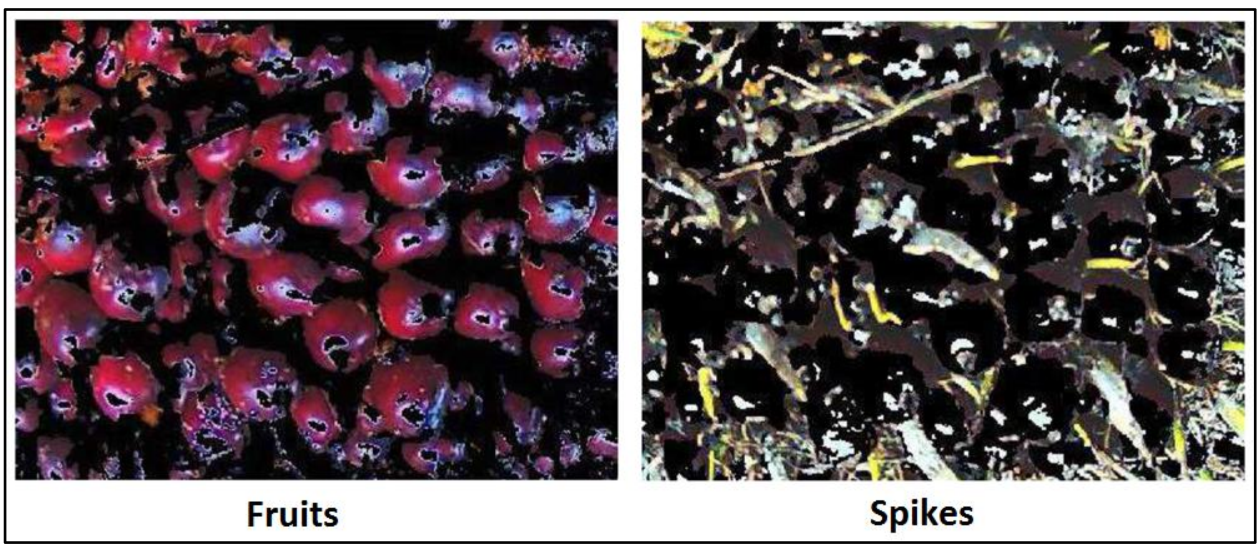


Figure 7: Image segmentation of FFB

2.3 Research Studies done and their results

According to the past research studies done under this study area it can be seen that the categories of FFBs considered were overripe, under-ripe and ripe. Research study in [1], [3] and [5] have considered categories overripe, under-ripe and ripe, research study in [12] has considered the categories under-ripe and ripe and the research in [11] has considered the categories ripe and under-ripe.

When considering the camera by which the images were captured it can be categorized into two major sections. Images captured in normal lighting environment by normal digital cameras and images captured in near infrared (NIR) range. Research studies in [1], [3] and [5] were done by capturing images in near infrared range (400nm to 1000 nm), while research studies in [2], [4], [11] and [12] were done in normal lighting. Research in [2] was done in outdoor environment.

When considering the accuracy of these past researches, study in [2] was experimented with 93.33% correctness in outdoor environment. Study in [3] claims more than 95% correctness for all three types of oil palm fruits. Study in [12] produced 100% correct outputs for ripe category but produced 20% and 25% error under ripe and unripe respectively.

The major feature that was used for image categorization is colour of the FFBs. According to research [12] only red colour was extracted and remaining parts were made black as red is the dominant colour in all FFBs.

Below are brief descriptions about research studies done in the past.

- **Near-infrared technique for oil palm fruit grading system – By Saeed, Osama Mohamed Ben (2013)**

According to [1] this is system developed in MATLAB 7.0 environment to classify FFBs. In this research, an oil palm grading system was built and an image processing technique algorithm was developed based on the spectral reflectance of the external features of oil palm fresh fruit bunches. Detection was done at near-infrared (NIR) range (400 nm to 1000 nm). Image processing approaches, such as image acquisition, image pre-processing, and image feature extraction, as well as image classification were developed to automate the ripeness grading for oil palm fruit bunches. The mathematical model was developed to determine the real value of the reflection of specific wavelengths for the three categories of oil palm FFBs (overripe, under-ripe and ripe) through regression analysis. The results were confirmed by a human trained grader.

- **Intelligent Color Vision System for Ripeness Classification of Oil Palm Fresh Fruit Bunch – By NorasyikinFadilah, Junita Mohamad-Saleh, Zaini Abdul Halim, Haidi Ibrahim, and Syed Salim Syed Ali (2012)**

According to [2] an algorithm was developed for automatic intelligent grading of oil palm FFB based on color vision in a natural light environment. This algorithm was able to classify the ripeness of oil palm FFBs with 93.33% correct classification in outdoor environment. Images of oil palm FFBs were collected and analyzed using digital image processing techniques. Then the color features were extracted from those images and used as the inputs for ANN learning.

- **Oil palm fruit grading using a hyper spectral device and machine learning algorithm – By O.M. Bensaeed , A.M. Shariff , A. B. Mahmud , H. Shafri,M. Alfatni (2014)**

According to [3] in this paper, a hyper spectral-based system was introduced to detect the ripeness of oil palm fresh fruit bunches (FFB). The FFBs were scanned using a hyper spectral device, and reflectance was recorded at different wavelengths. A total of 469 fruits from oil palm FFBs were categorized as overripe, ripe, and under-ripe. Fruit attributes in the visible and near-infrared(400 nm to1000 nm) wavelength range regions were measured. Artificial neural network (ANN), classified the different wavelength regions on oil palm fruit through pixel-wise processing. The developed ANN model successfully classified oil palm fruits into the three ripeness categories (ripe, under-ripe, and over-ripe). The accuracy achieved by this approach was compared against that of the conventional system employing manual classification based on the observations of a human grader. This classification approach had an accuracy of more than 95% for all three types of oil palm fruits.

- **Image Processing Analysis of Oil Palm Fruits for Automatic Grading**

According to [12] in this study colour density was analyzed to determine the ripeness of each bunch. Categories considered; under ripe, unripe and ripe. Background colour was removed from FFB images. Since red colour is dominant in every bunch category, other colours were removed and changed to black colour as they return 0 and do not affect the next process of colour filtering. Below image shows red intensity for each category. Ripe category produced 100% correct outputs but under ripe and unripe had 20% and 25% error respectively.

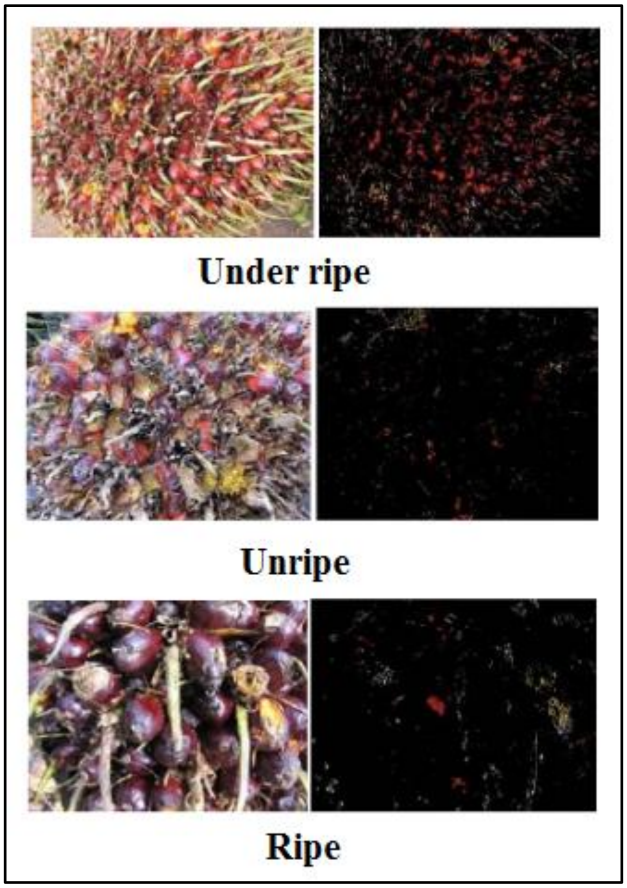


Figure 8: Red intensity of each category

Mean of red component for each category is shown in below figure.

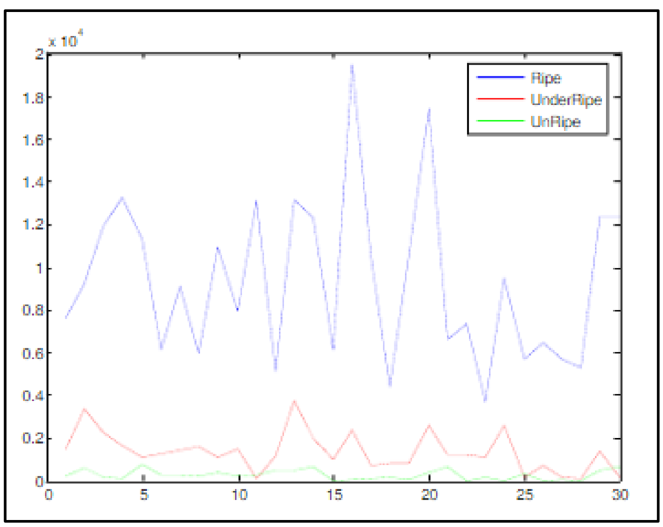


Figure 9: Mean of red component for each category

- **A Portable Low-cost Non-destructive Ripeness Inspection for Oil Palm FFB – By Muhammad Makky (2015)**

According to [4] in this study, the ripeness of oil palm fresh fruits bunch (FFB) was assessed using a portable and low-cost device, comprised of digital camera, laptop and a small and lightweight chamber equipped with independent LED lights. First, the FFB sample was observed by three experts to evaluate its ripeness. Then the sample was placed inside the chamber and was recorded by camera. In order to record the whole bunch, camera was positioned perpendicularly 1 meter above the ground, facing down toward the FFB. The recorded FFB image was subsequently segmented and analyzed using the image processing software in the computer. The software calculated and specified the color of the FFB image in RGB color space. The results were then compared with the observations by the panelists. In this study, FFB color observations by the camera vision, produced better consistency compared to the observations results from the experts.

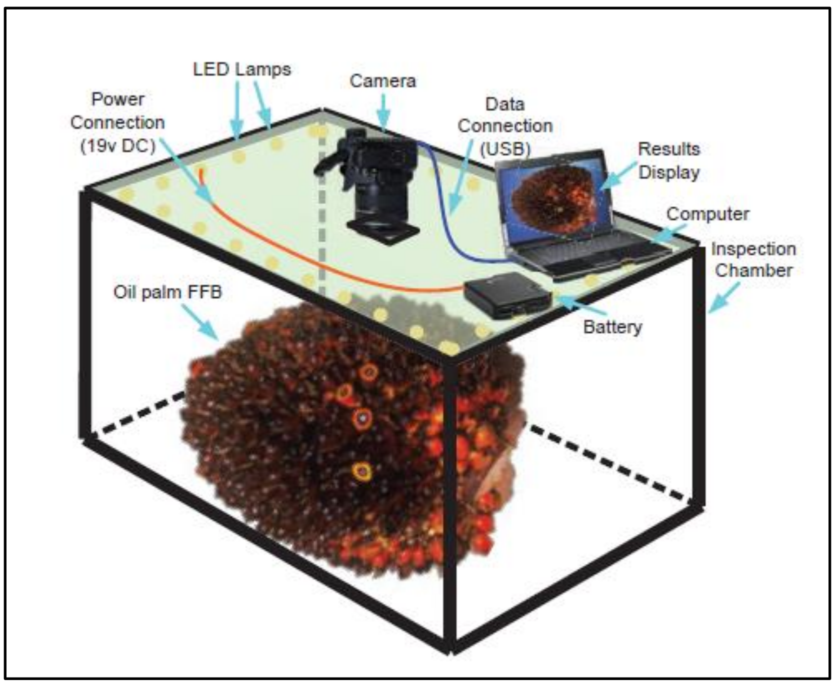


Figure 10: Portable device

- **Ripeness Detection of Oil Palm Fresh Fruit Bunches Using 4-Band Sensors**

According to [5], in this study the 4-Band Sensor equipment consists of the following bands: 660 nm, 780 nm, 870 nm and 970 nm. Data analysis using the T-test method was performed to inspect three classes of palm fresh fruit bunches ripeness; under-ripe, ripe and over-ripe categories. This paper focuses on reflectance acquisition, which can reveal the essential information of interest using the visible and near-infrared bands of radiation. The laboratory results demonstrate that the 4-Band Sensors can distinguish ripe, under-ripe and over-ripe categories. Only the 780 nm band differed significantly when the T-test statistical method was applied to differentiate the three categories. The three best indicators have been identified, which are the 780 nm band, interaction between the 780 nm band and the 870 nm band as well as the 870 nm band. The indicators were ranked utilizing the chi-square method. The highest classification accuracy was 83% using the Support Vector Machine method. This study has greatly explored the potential of hand-held equipment using spectral technology to be utilized commercially as it is affordable, suitable and useful for the palm oil industry in general and specifically useful for palm oil mills, plantation sectors and small holders.

- **Assessment of palm oil fresh fruit bunches using photogrammetric grading system**

According to [11] an automated grading system was implemented for palm oil FFB using a computer assisted photogrammetric methodology that is able to correlate the surface color of fruit bunches to their ripeness and thereafter sort the fruit into two predefined fruit categories; ripe and unripe. The methodology consists of five main phases, i.e. image acquisition, image pre-processing, image segmentation, calculation of color DN and finally the classification of ripeness. This was implemented using MATLAB package. The fruit classification ability of the system above yielded above 90% accuracy and less than 25 seconds for the classification of the fruit bunches. Below image shows the GUI for FFB grading.

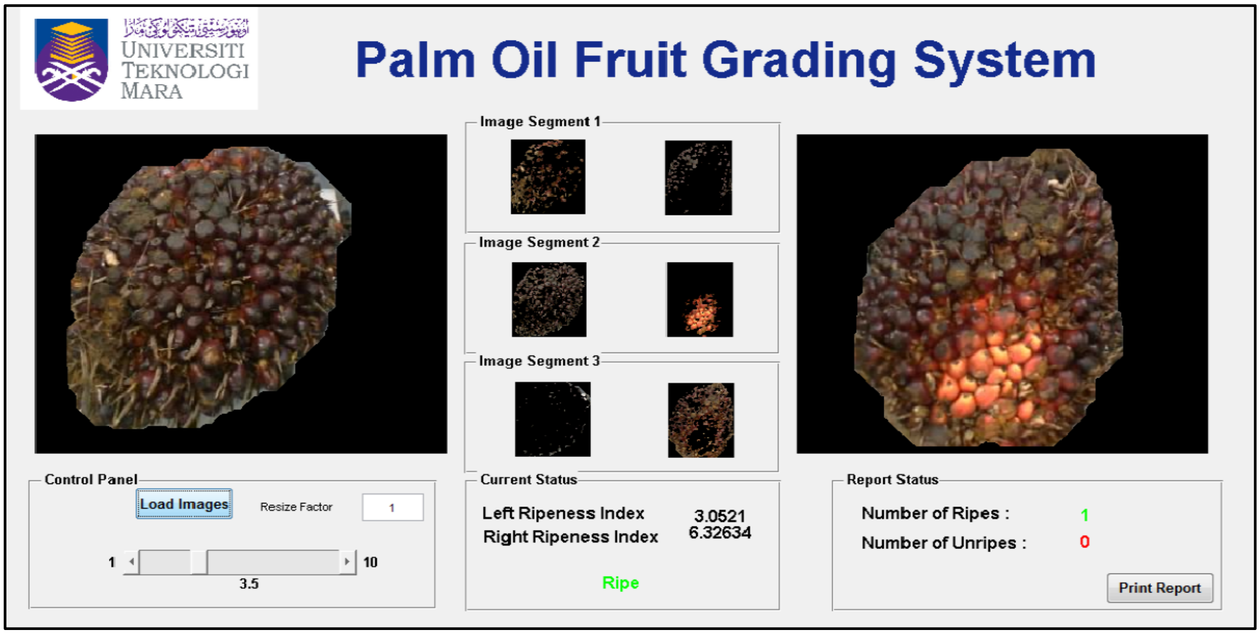


Figure 11: GUI for FFB grading system

CHAPTER 3

METHODOLOGY

For successful automation of mill grading process, different categories of palm bunches (riped bunches, under riped bunches, over riped bunches, dirty bunches and empty bunches) should be properly recognized. Colour texture and shape of the bunch has to be identified. An algorithm has to be developed for this purpose for successful identification and categorization of palm bunches.

Based on past researches and studies done, certain image processing facilities available in MATLAB can be utilized in this research for noise removal, segmentation etc. However certain facilities may not be available or be less accurate. The improvement of those areas would be a challenge that needs to be addressed in this research study.

This section discusses about the proposed methodology which is subject to changes in implementation stages.

3.1 Proposed Solution

As illustrated in figure 12, the palm bunch would be placed in front of a digital camera in an indoor environment and the image will be captured. Captured image has to be processed using the application using MATLAB features and new algorithms developed. Background has to be removed to get rid of noises. Colour, texture, shape and size need to be recognized for successful processing.

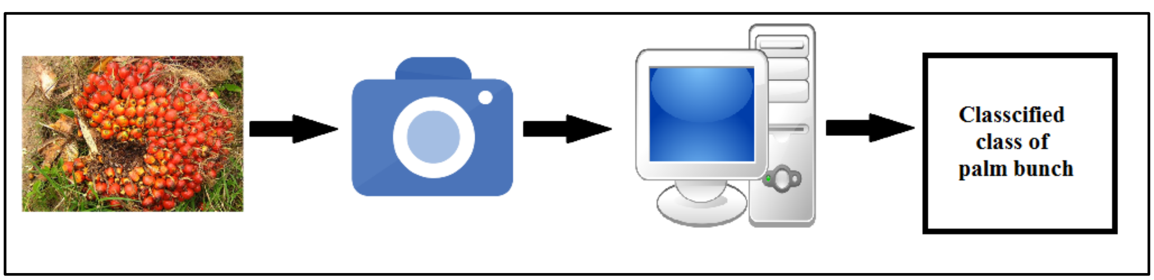


Figure 12: High level diagram of proposed solution

CHAPTER 4

SOLUTION ARCHITECTURE

The solution is produced in five main phases; they are image loading, image pre-processing, image segmentation, Calculation and classification of FFBs based on ripeness.

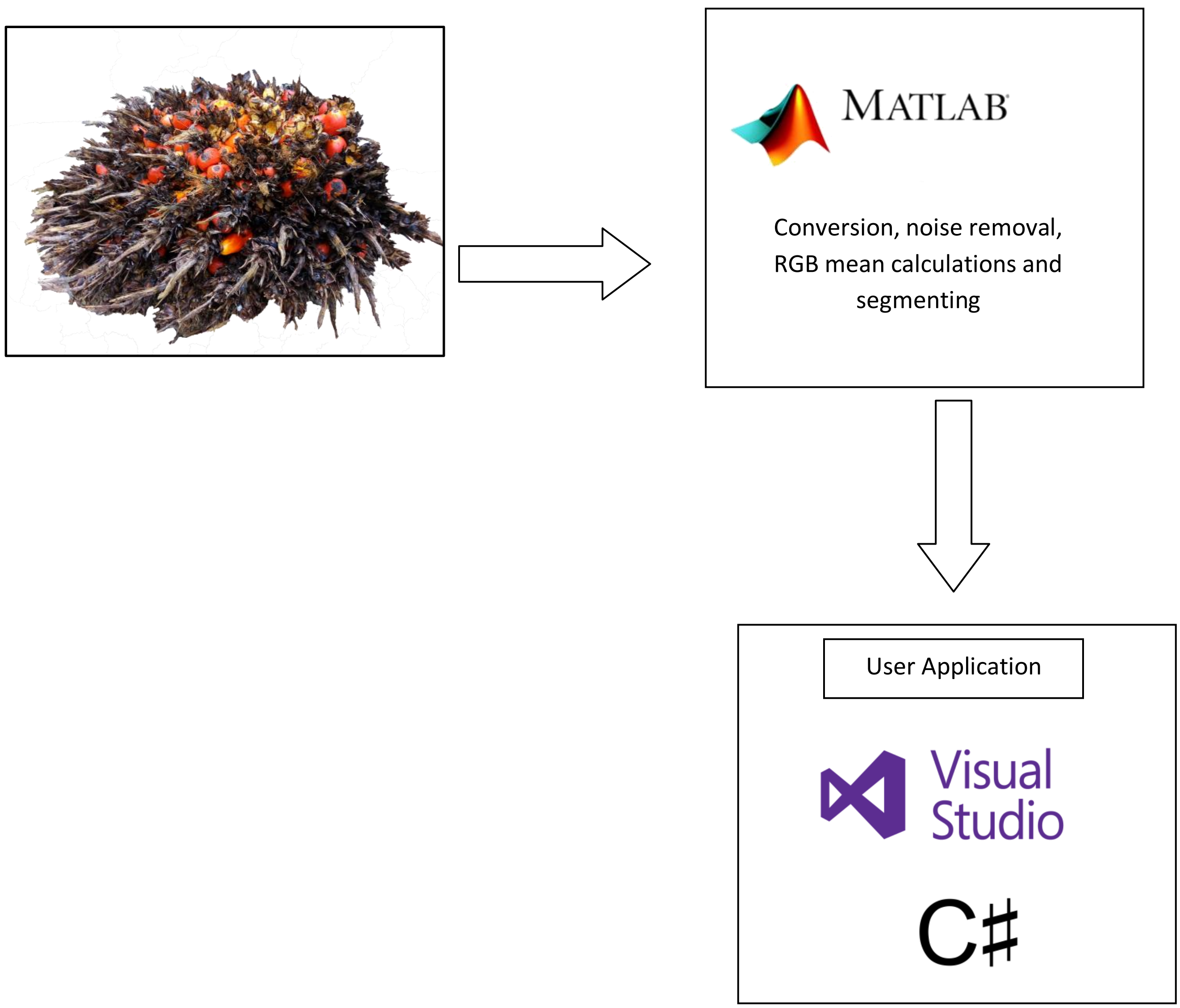


Figure 13: The process of FFB classification

4.1 Image Loading

Image loading is the process of retrieving the image from the source into the application. The image which is captured through a digital camera in indoor environment needs to be loaded to the application. Below image shows the loaded image in MATLAB.

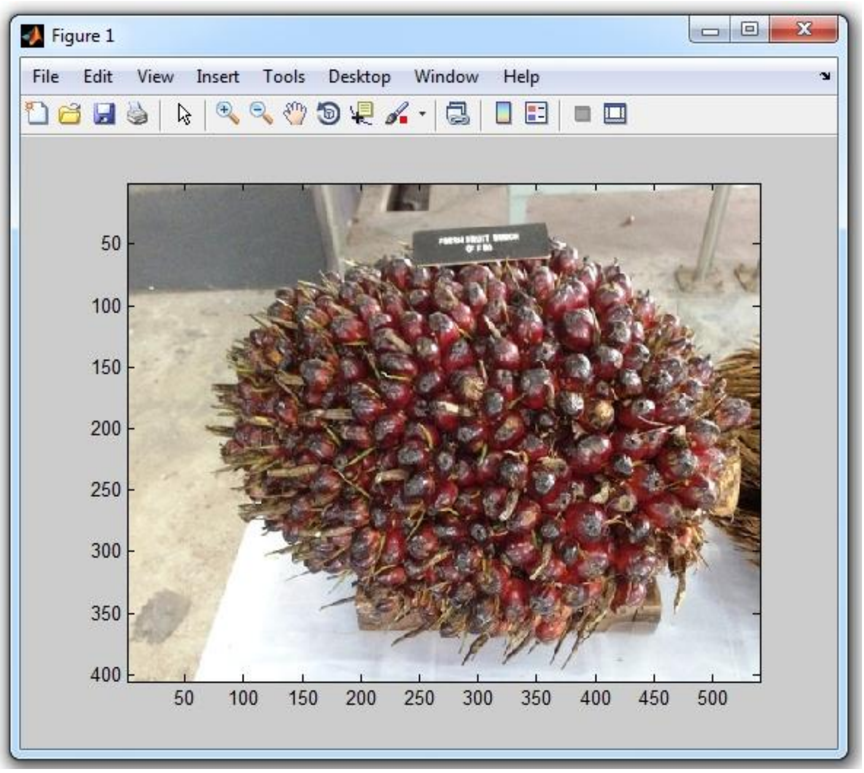


Figure 14: Loaded image in Matlab

4.2 Image Pre-processing

This is the phase in which background noise has to be removed for more accurate result. Noise may be present in the image because of shadows, variations in brightness and unrelated parts in the image of FFB. To remove noise in MATLAB, mask operation can be applied. The mask can be created by using image binarization, morphological processing and FFB properties extraction.

- **Image Binarization**

This is the process of converting the image into binary. In this step the RGB image is converted to gray colour and then to binary image. Then the binary image is converted to inverse binary image. The inverse binary image will invert the object represented in white (binary value 1) and the background indicated by black (binary value 0).

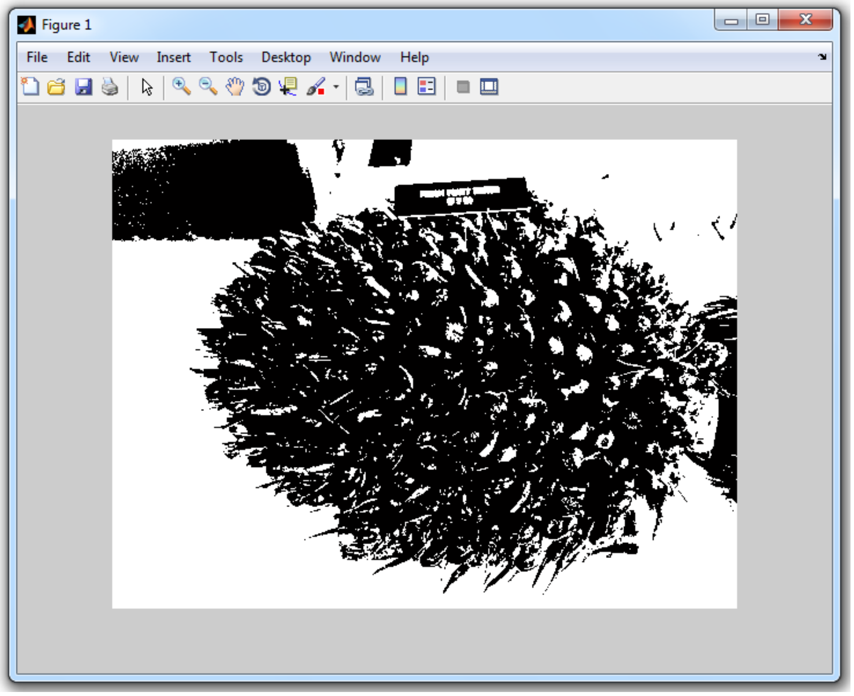


Figure 15: Binarized image

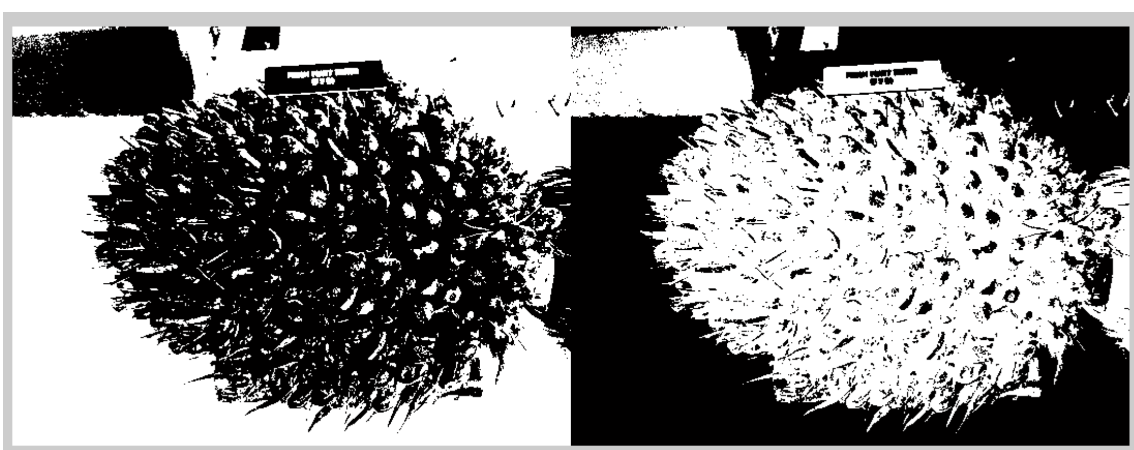


Figure 16: Inverse binary image

- **Morphological Processing**

The binarized image in figure 16 shows that there are gaps and holes**.** In this step the holes and gaps found in the interior of the image are filled as shown below.

Figure 17: Gaps removed image

- **FFB properties extraction**

  Each and every object in the binary image needs to be identified. Pixels identified as '0' is the background. Using the pixel information, the largest object is identified which is the FFB.

4.3 Image Segmentation

Determining the ripeness of palm fruits using average color Digital Number (DN) values in RGB color space is difficult as palm fruit images are usually mixed with dirt and branches. The most suitable colour space for the measuring of colour in palm fruits is L*a*b* color space. In this step by using the L*a*b* Color Space and K-means clustering the image is segmented into many parts. Then the DN value is calculated for each part.

This steps involves cropping of the image, converting the image from RGB colour space to L*a*b* color space and segmenting the image using K-means clustering algorithm.

- **Image Cropping**

Image is cropped to reduce image and to get the relevant part of the image. Computational speed will also be improved by image cropping.

- **RGB to L*a*b* Color Space Conversion**

This conversion is done as images in RGB space does not represent color according to human perception.

- **Segmentation of FFB image Using K-Means Clustering algorithm**

Clustering algorithm is used to identify hidden patterns and grouping in-order to measure similarity. "K-Means clustering" approach was selected as it partitions data into K distinct clusters based on distance to the centroid of a cluster.

According to the research in [25], K-Means Clustering algorithm is the most suitable algorithm for segmenting FFB images. K-means algorithm partitions the observations of the images into K mutually exclusive clusters, and returns a vector of indices indicating to which of the K clusters it has assigned for each observation.
This algorithm finds a partition in which an object within each cluster is as close to each other as possible, and as far from objects in other clusters as possible. The distances between objects can be measured by using the Euclidean distance metric.

4.4 Mean RGB Calculation

As colour is a major feature in determining the ripeness calculation, the mean RGB of the FFB is necessary. Red is the dominant colour in riped fruits. A range (minimum and maximum) should be obtained for each Red, Green and Blue values for each category. Based on the mean Red intensity, it can be identified if the bunch is ripe or not.

4.5 Integration of MATLAB with .NET

MATLAB can be integrated with .NET framework. The matnet .NET can be used to access MATLAB functionalities from .NET applications. The matnet library can be used to work directly with MATLAB or to expose M-files as components; it's also possible to interact with the imaging toolbox and bitmaps. The matnet library can be used to access a custom DLL library also.

CHAPTER 5

SYSTEM EVALUATION (DATA AND ANALYSIS)

5.1 Color-Based Segmentation Using K-Means Clustering

By using L* a*b* colour space and K-means clustering, the image was segmented [20]. The image that was initially in RGB colour space was converted to L* a*b* colour space as it is more easy to distinguish the colours. Objects in the image were segmented into three clusters using Euclidean distance metric. Mean RGB values were taken for 45 images in each category.

5.1.1 Test Data For Ripe FFB

Image 1

Mean Red value: 152.08

Mean Green value: 75.62

Mean Blue value: 59.89

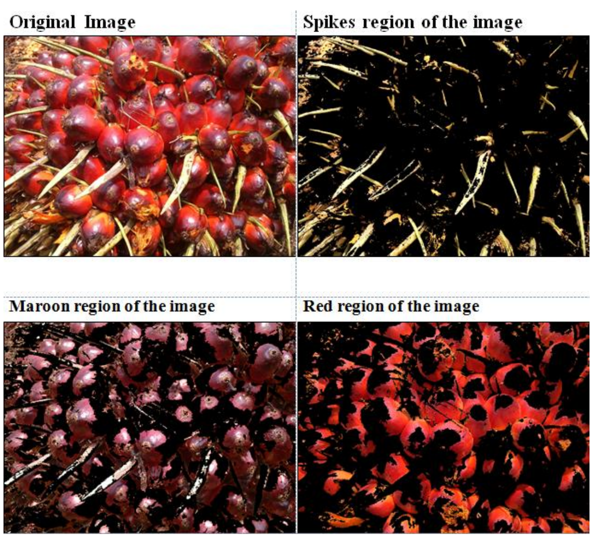


Figure 18: Different segments of image 1

Image 2

Mean Red value: 139.72

Mean Green value: 69.93

Mean Blue value: 52.51

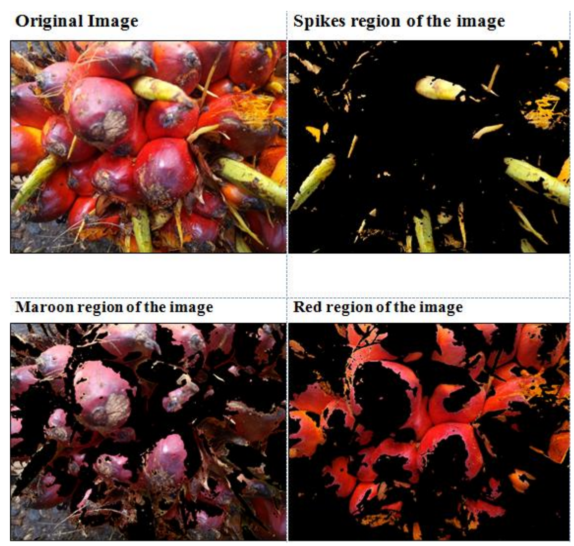


Figure 19: Different segments of image 2

The above images show the different features of the fruit bunch extracted into different segments. They are the spike region, maroon region and red region.

Appendix A presents the enlarged images.

Below Histograms show the RGB intensities of ripe FFBs.

Histograms of Image 1

Histograms of Image 2

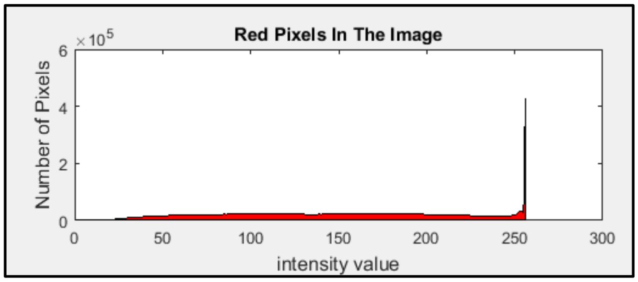


Figure 20: Histogram - red pixels in image 1

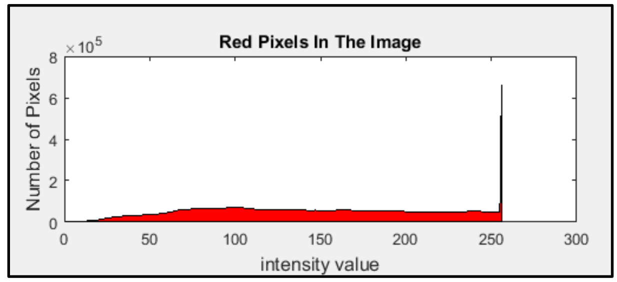


Figure 21: Histogram - red pixels in image 2

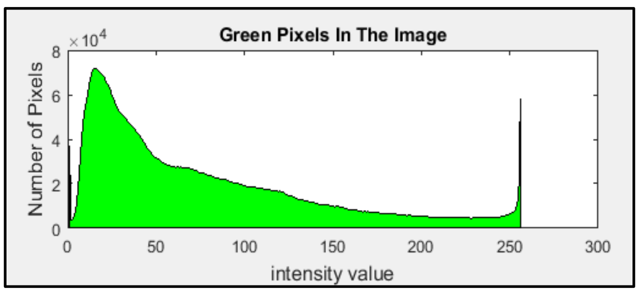


Figure 22: Histogram - green pixels in image 1

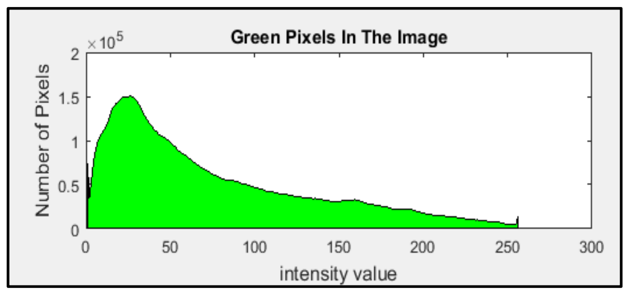


Figure 23: Histogram - green pixels in image 2

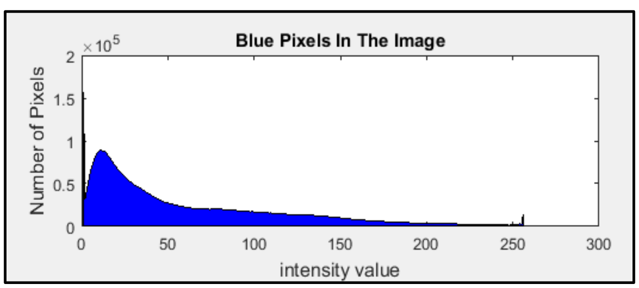


Figure 24: Histogram - blue pixels in image 1

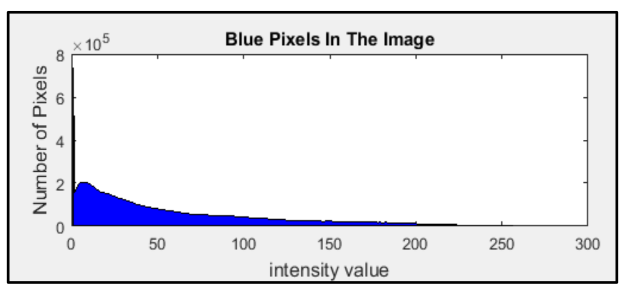


Figure 25: Histogram - blue pixels in image 2

Appendix B presents a table with mean RGB intensities of all tested images.

5.1.2 Test Data For Under Ripe FFB

Image 1

Mean Red value: 94.05

Mean Green value: 79.58

Mean Blue value: 74.74

Image 2

Mean Red value: 98.65

Mean Green value: 83.89

Mean Blue value: 76.53

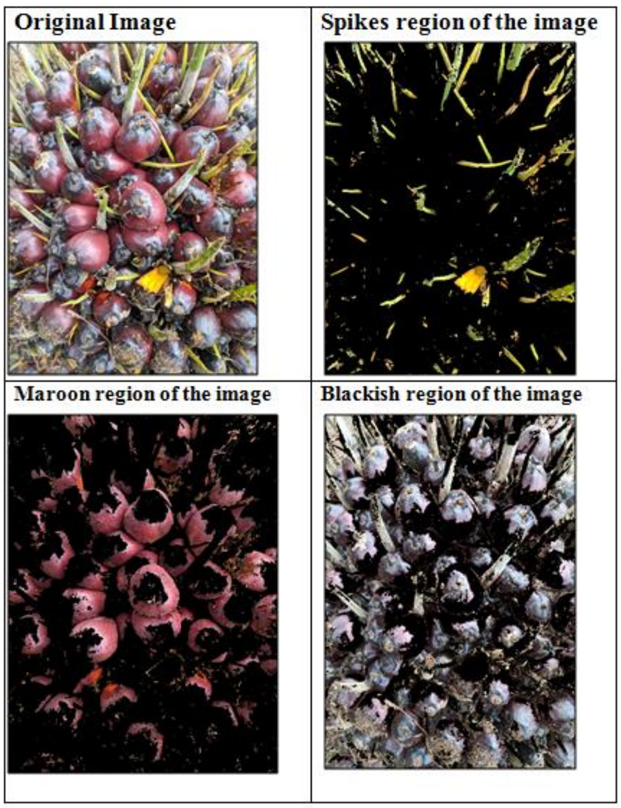


Figure 26: Different segments of image 1

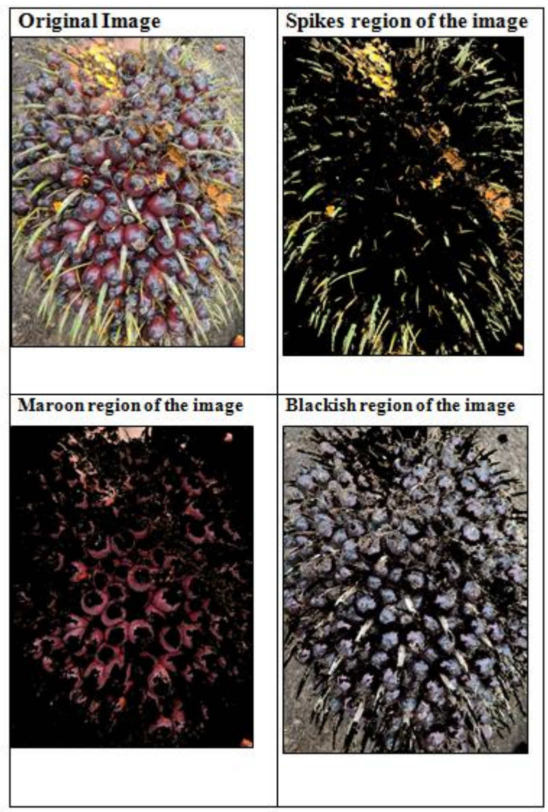


Figure 27: Different segments of image 2

The above images show the different features of the fruit bunch extracted into different segments. They are the spike region, maroon region and blackish region.

Appendix A presents the enlarged images.

Below Histograms show the RGB intensities of under ripe FFBs.

Histograms of Image 1

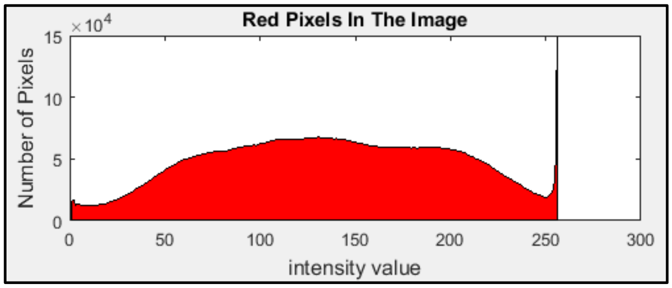


Figure 28: Histogram - red pixels in image 1

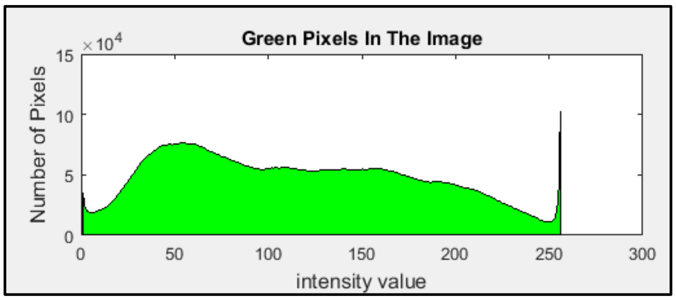


Figure 30: Histogram - green pixels in image 1

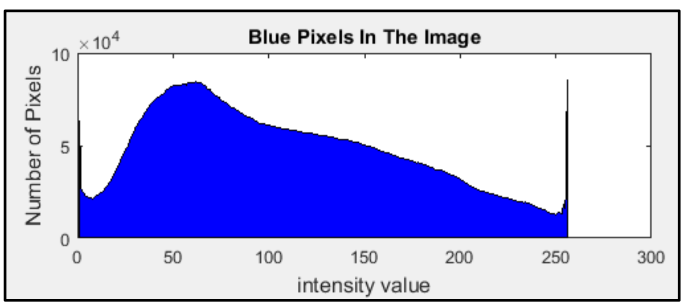


Figure 32: Histogram - blue pixels in image 1

Histograms of Image 2

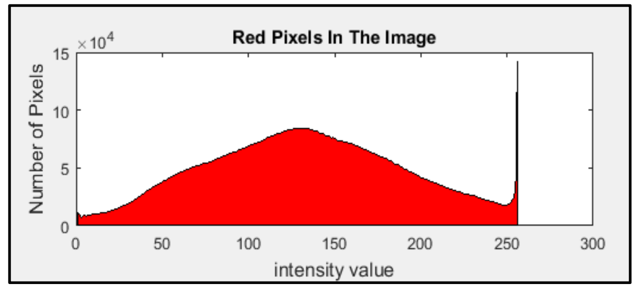


Figure 29: red pixels in image 2

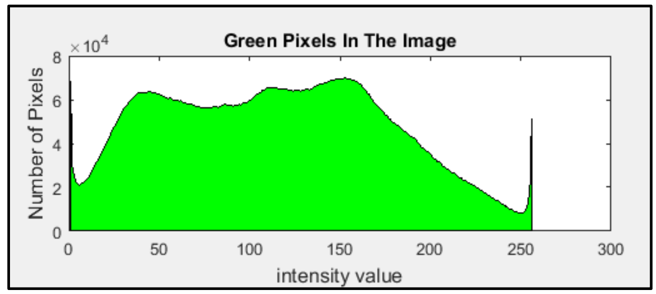


Figure 31: Histogram - green pixels in image 2

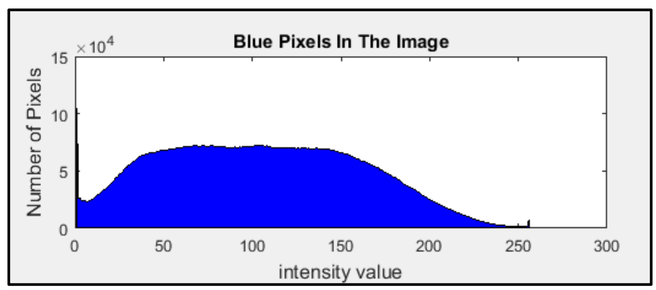


Figure 33: Histogram - green pixels in image 2

Appendix B presents a table with mean RGB intensities of all tested images.

5.1.3 Test Data For Over Ripe FFB

Image 1		**Image 2**	
Mean Red value:	95.62	Mean Red value:	49.87
Mean Green value:	68.79	Mean Green value:	36.71
Mean Blue value:	57.52	Mean Blue value:	33.49

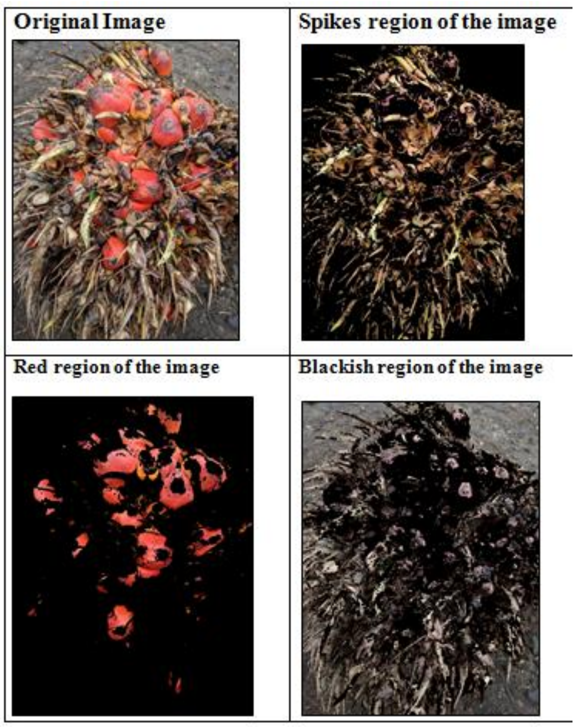


Figure 34: Different segments of image 1

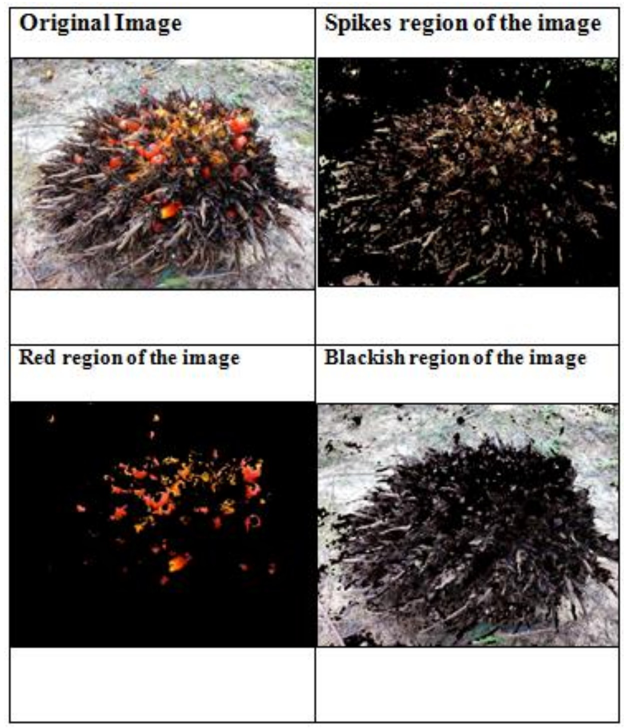


Figure 35: Different segments of image 2

The above images show the different features of the fruit bunch extracted into different segments. They are the spike region, red region and blackish region.

Appendix A presents the enlarged images.

Below Histograms show the RGB intensities of over ripe FFBs.

Histograms of Image 1

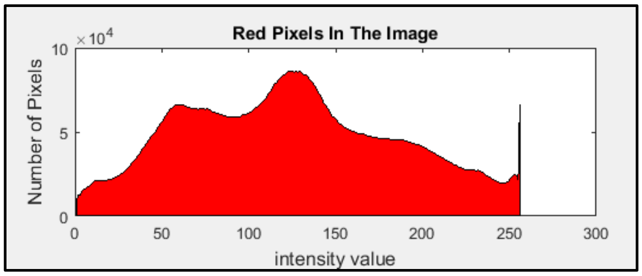


Figure 36: Histogram - red pixels in image 1

Histograms of Image 2

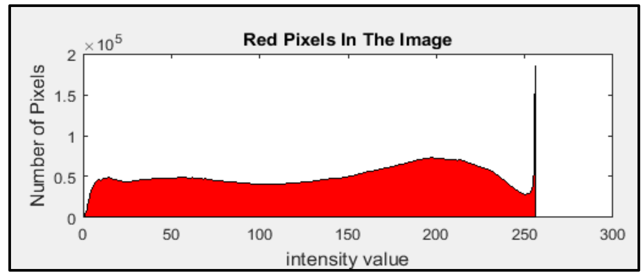


Figure 37: Histogram - red pixels in image 2

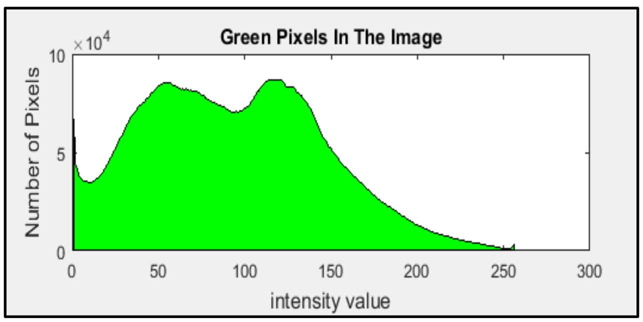


Figure 38: Histogram - green pixels in image 1

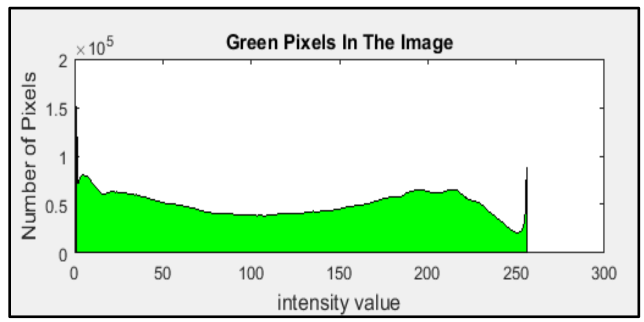


Figure 39: Histogram - green pixels in image 2

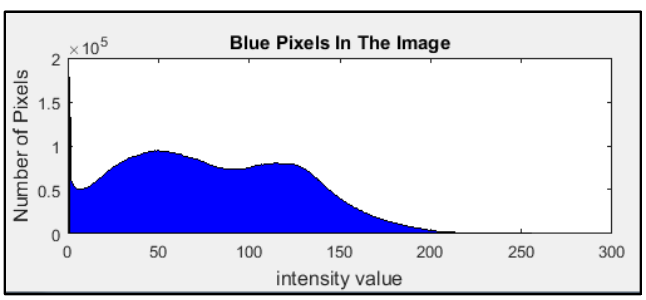


Figure 40: Histogram - blue pixels in image 1

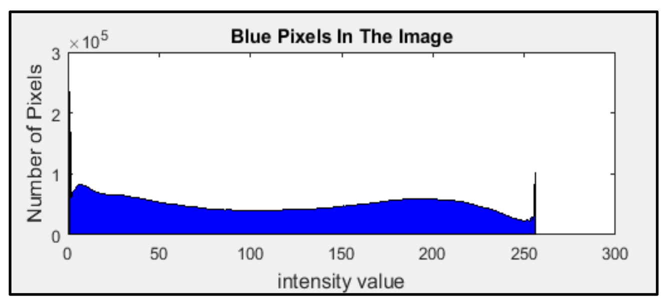


Figure 41: Histogram - blue pixels in image 2

Appendix B presents a table with mean RGB intensities of all tested images.

5.1.4 Comparisons And Analysis

From the above histograms it can be seen that both under ripe and over ripe categories are having a higher percentage of blue and green pixels more than red pixels. But only the images in ripe category are having a greater percentage of red pixels.

From the tables in appendix B it can be understood that the ripe fruit bunches had mean red value more than 100 except for 3 exceptional cases. In both under-ripe and over-ripe categories the mean R value was below 100. Based on the minimum and maximum values of RGB from the experiment results, the ranges of the colours of each category is shown in the below table.

	Red Range	**Green Range**	**Blue Range**
Ripe Category	100.88<R < 158.10	41.52< G < 107.50	20.84 < B < 80.30
Under Ripe Category	43.37 < R < 80.59	24.29 < G < 83.90	17.04 < B < 80.58
Over Ripe Category	47.87 < R < 95.62	24.29 < G < 81.40	11.56 < B < 87.15

Table 1: RGB Range for each category

5.2 Identification of Maximum Peaks

5.2.1 Test Data For Ripe FFB

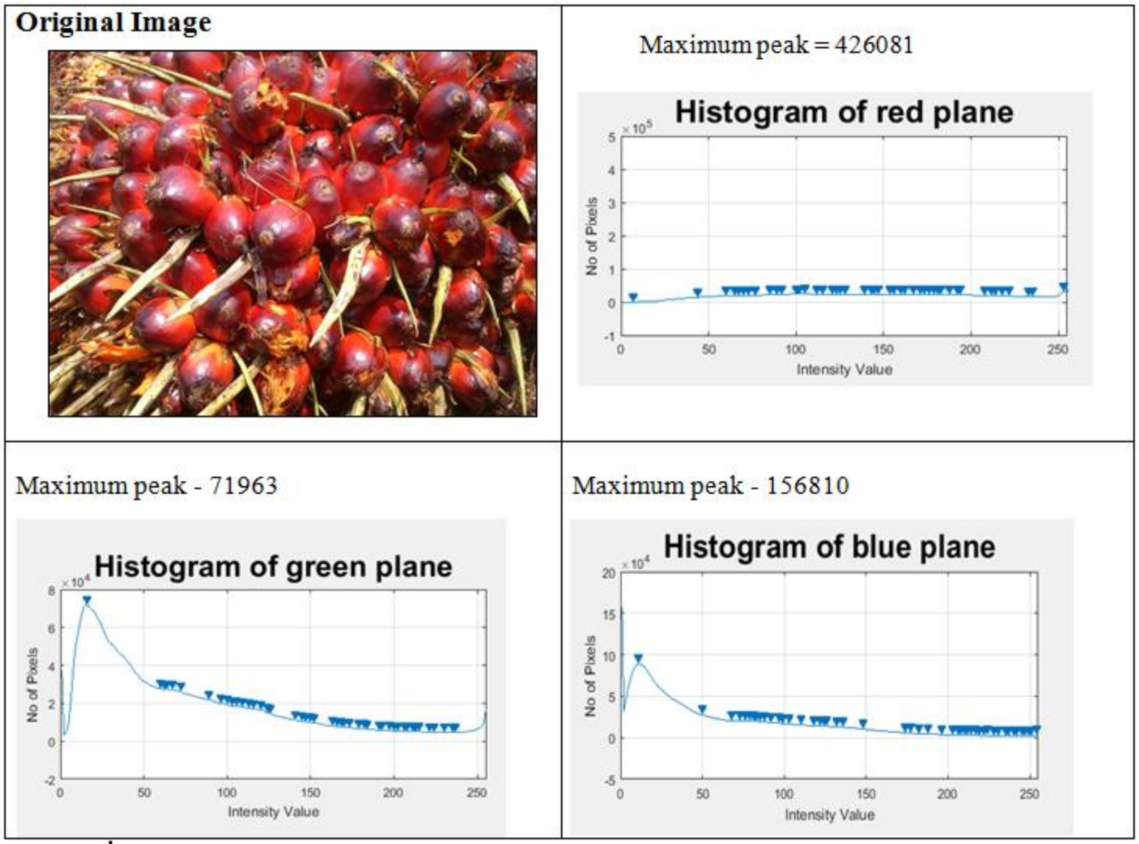


Figure 42: Maximum peaks in RGB planes – Ripe category

5.2.2 Test Data For Under Ripe FFB

Original Image

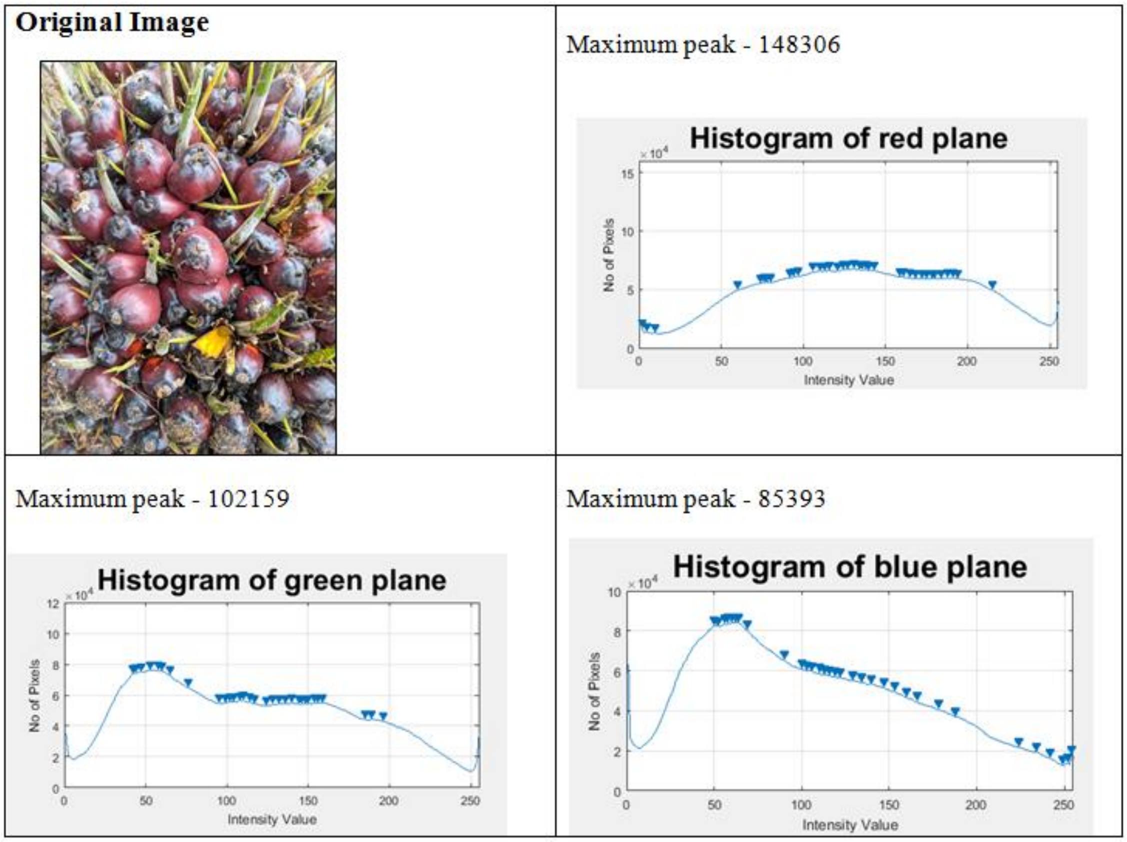


Figure 43: Maximum peaks in RGB planes – Under ripe category

5.2.3 Test Data For Over Ripe FFB

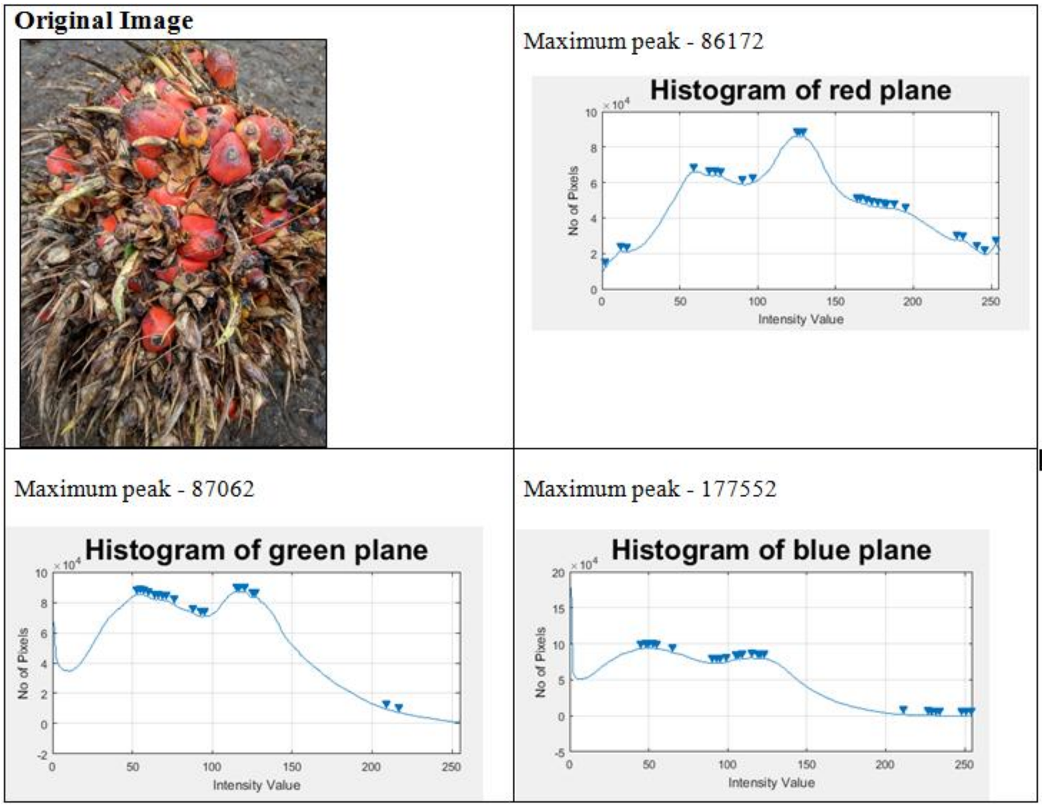


Figure 44: Maximum peaks in RGB planes – Over ripe category

5.2.4 Comparisons And Analysis

Image	Maximum Red Peak	Maximum Green Peak	Maximum Blue Peak
Under Ripe Image 1	148306	102159	85393
Under Ripe Image 2	141759	70128	103992
Under Ripe Image 3	195379	87075	94790
Under Ripe Image 4	186592	73075	139160
Under Ripe Image 5	147187	74096	71089
Ripe Image 1	426081	71963	156810
Ripe Image 2	659016	150914	733624
Ripe Image 3	2510307	162809	750855
Ripe Image 4	119106	52195	53316
Ripe Image 5	519550	115160	681122
Over Ripe Image 1	86172	87062	177552
Over Ripe Image 2	185327	150212	235742
Over Ripe Image 3	286014	94991	162355
Over Ripe Image 4	65940	66303	88299
Over Ripe Image 5	135269	88002	116746

Table 2: RGB Peak values of test images

The above table shows the maximum peak value of red, green and blue channels of five images of each category.

From this test it was identified that there were no uniform patterns. Different peak levels or the maximum peak value could not be taken for analysis.

5.3 Finding The Largest Object Area

Since the ripe category can be distinguished from mean RGB values the other two category images were used for testing the largest object area of the image.

First the entire objects area was calculated by converting the image to grey scale and thereafter filling the background with a known colour. Then the image's area and known colour's area was calculated separately and the bunch's area was calculated based on the difference in the area. According to [22] and [23] the image was binarized and the area of the biggest blob was obtained.

5.3.1 Test Data For Under Ripe FFB

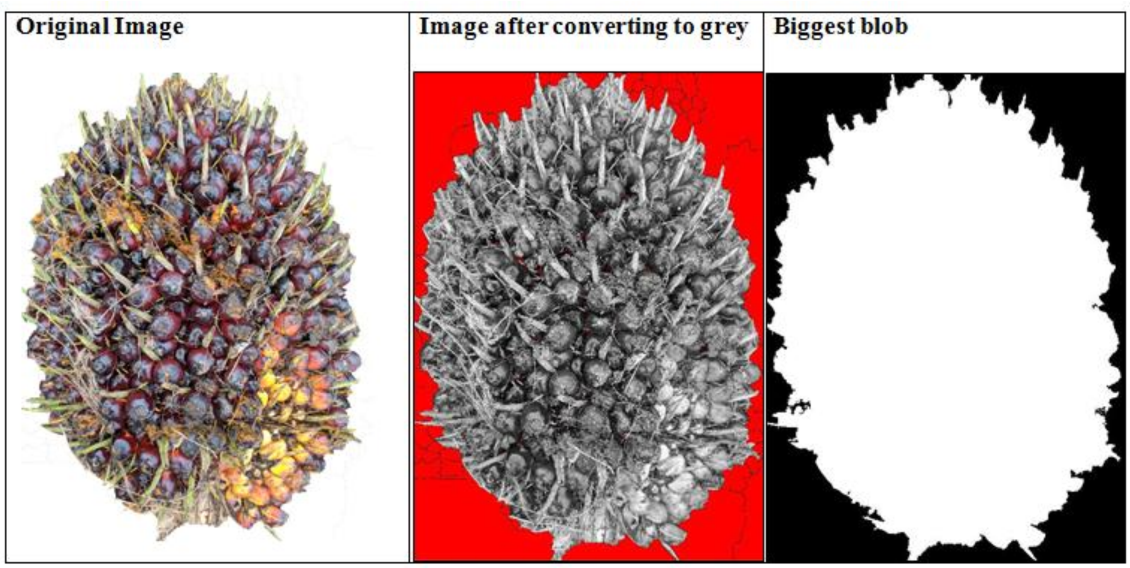


Figure 45: Extracting biggest blob – Under ripe category

Appendix C presents a table with blob areas of all tested images.

5.3.2 Test Data For Over Ripe FFB

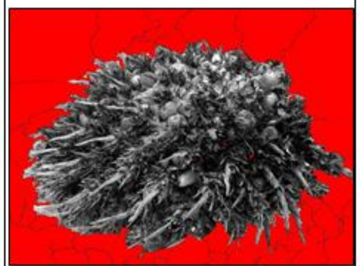
Original Image	Image after converting to grey	Biggest blob
		

Figure 46: Extracting biggest blob – Over ripe category

Appendix C presents a table with blob areas of all tested images.

5.3.3 Comparisons And Analysis

Under ripe bunches have less than 10 lose fruits in a bunch while over ripe bunches have more than 50% of the fruits detached [21]. Under ripe bunch is usually full of fruits while over ripe has lesser fruits and more spikes and husks.

The largest connected filled area was considered as the biggest blob. The feature colour alone was not sufficient to decide the category. Therefore the other feature that the under-ripped bunches are mostly full of fruits and under-riped bunches have most area as empty husk was used in this research.

From the test data provided in Figure 47 and Figure 48 it can be analyzed that the under –ripe bunches have the biggest blob area of more than 50% of the entire bunch and under ripe bunches have less than 50% of the biggest blob area. Most of the over ripe bunches had the percentage blob between 5% - 45%. Most of the under ripe bunches had the percentages between 50% - 90%.

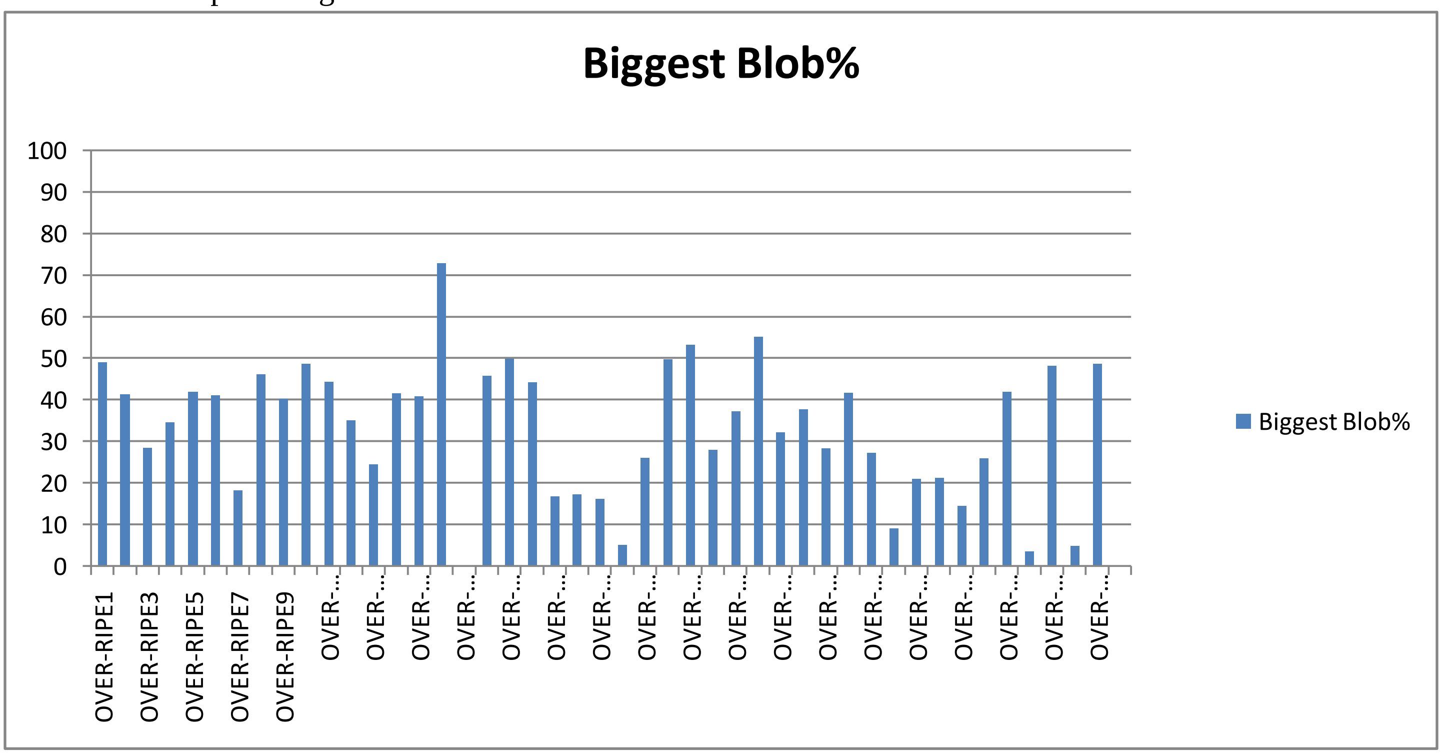


Figure 47: Percentage of biggest blob of over-ripe bunches

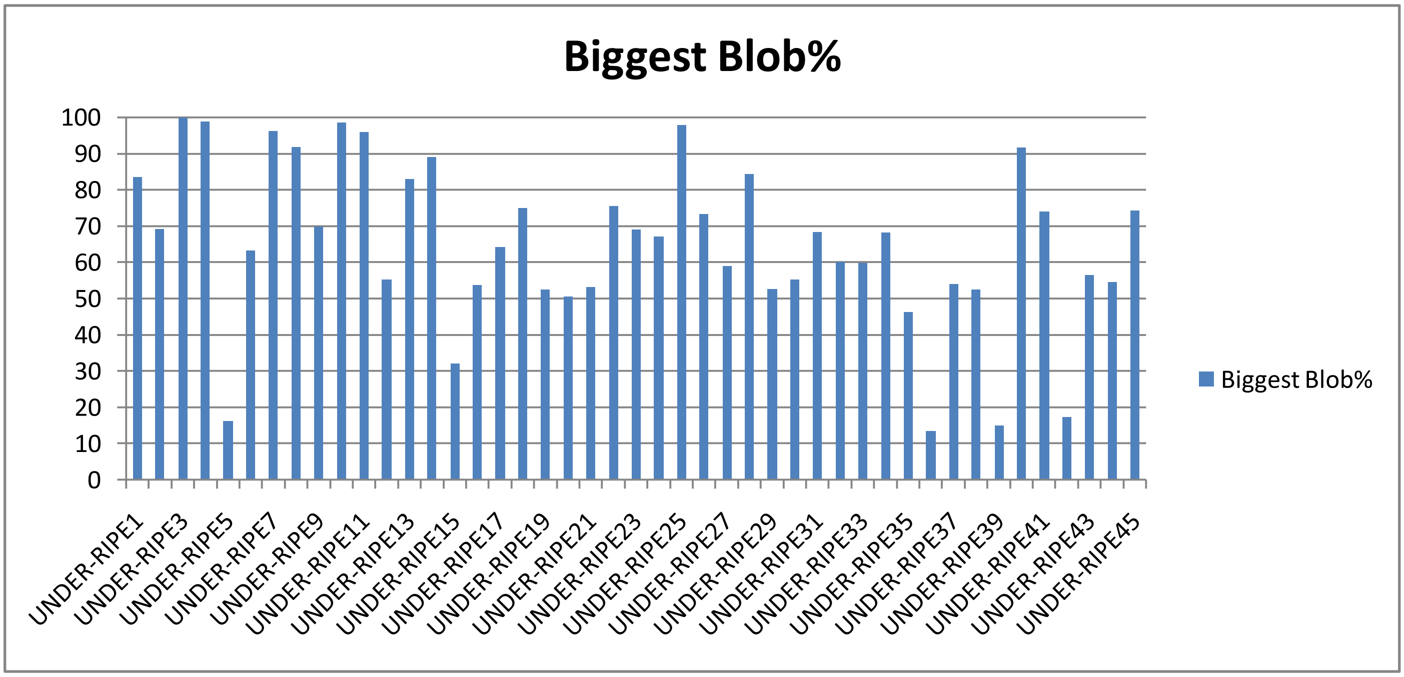


Figure 48: Percentage of biggest blob of under-ripe bunches

5.4 The FFB Ripeness Classifier

"FFB Ripeness Classifier" is the application developed in a user friendly way that the image of FFB can be selected and the results can be viewed. Given below are results of few test images.

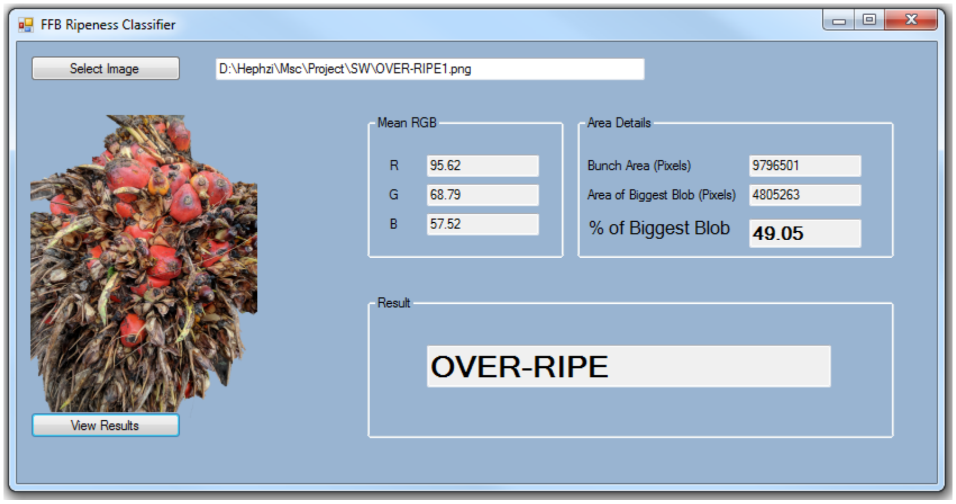


Figure 49: Screenshot of classification by the FFB Ripeness Classifier

As shown in the above image, this application provides the RGB intensities of the image and also the bunch area and area of biggest blob in pixels. Also it provides the percentage of the biggest blob. Finally it provides to which category the bunch belongs to.

5.5 Test Results Analysis

Ten images were taken in each category separately and the test was carried out three times. Below tables table 4, table 5 and table 6 display the results obtained.

Pass: The system categorized category was same category as expected.

Fail: The system categorized category was different category than expected.

Confusion matrix

The below table provides the confusion matrix based on the test done for the three categories.

	Under-Ripe	Ripe	Over-Ripe
Under-Ripe	40	04	01
Ripe	02	42	01
Over-Ripe	00	03	42

Table 3: Confusion Matrix

Category: Under Ripe

Test 1		Test 2		Test 3	
Image ID	Result	Image ID	Result	Image ID	Result
1	PASS	2	PASS	4	PASS
12	PASS	3	PASS	6	PASS
15	PASS	5	FAIL	7	PASS
20	PASS	6	PASS	18	PASS
22	PASS	8	PASS	21	PASS
25	PASS	10	PASS	24	PASS
27	PASS	14	PASS	28	PASS
30	PASS	17	PASS	29	PASS
34	PASS	23	PASS	36	FAIL
40	PASS	26	PASS	42	FAIL
Pass Rate	100%	Pass Rate	90%	Pass Rate	80%

Table 4: Results of test performed for under-ripe category

Category: Ripe

Test 1		Test 2		Test 3	
Image ID	Result	Image ID	Result	Image ID	Result
3	PASS	1	FAIL	9	PASS
4	PASS	7	PASS	13	PASS
6	PASS	14	FAIL	25	PASS
8	PASS	19	PASS	26	PASS
10	PASS	22	PASS	29	PASS
11	PASS	28	PASS	31	PASS
15	PASS	29	PASS	34	PASS
20	PASS	33	PASS	38	PASS
35	PASS	43	PASS	39	PASS
40	PASS	45	PASS	41	PASS
Pass Rate	100%	Pass Rate	80%	Pass Rate	100%

Table 5: Results of test performed for ripe category

Category: Over Ripe

Test 1		Test 2		Test 3	
Image ID	Result	Image ID	Result	Image ID	Result
1	PASS	3	PASS	2	PASS
4	PASS	8	PASS	6	PASS
5	PASS	11	PASS	14	PASS
7	PASS	19	PASS	16	PASS
10	PASS	22	PASS	23	PASS
15	PASS	31	PASS	33	PASS
18	PASS	38	PASS	36	PASS
25	FAIL	39	FAIL	40	PASS
27	PASS	42	FAIL	43	PASS
35	PASS	45	PASS	44	PASS
Pass Rate	90%	Pass Rate	80%	Pass Rate	100%

Table 6: Results of test performed for over-ripe category

The below table shows the precision and recall values derived from values obtained through confusion matrix.

	Precision (true positive)	**Recall (false negative)**
Under Ripe	42/49	42/45
Ripe	42/44	42/45
Over Ripe	40/42	40/45

Table 7: Precision and Recall values of all three categories

$$F_1 = \left[(precision * recall) \div (precesion + recall)\right] * 2$$

The above equation was applied to all three categories to calculate the accuracy.

1. Ripe

$$F_1 = \left\{\left[(42/45) \times (42/49)\right] \div \left[(42/45) + (42/49)\right]\right\} \times 2$$

= 0.89

89% accuracy for ripe category

2. Under Ripe

$$F_1 = \left\{\left[(40/42) \times (40/45)\right] \div \left[(40/42) + (40/45)\right]\right\} \times 2$$

= 0.919

92% accuracy for under ripe category

3. Over Ripe

$$F_1 = \left\{\left[(40/44) \times (42/45)\right] \div \left[(40/44) + (42/45)\right]\right\} \times 2$$

= 0.92

92% accuracy for ripe category

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APPENDIX

Appendix A Image 1 – Ripe Category

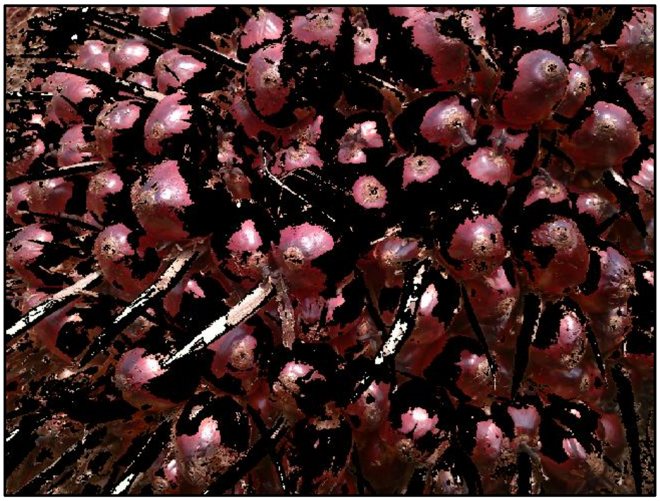
Original Image	Spikes region of the image
	
Maroon region of the image	**Red region of the image**
	

Image 2 – Ripe Category

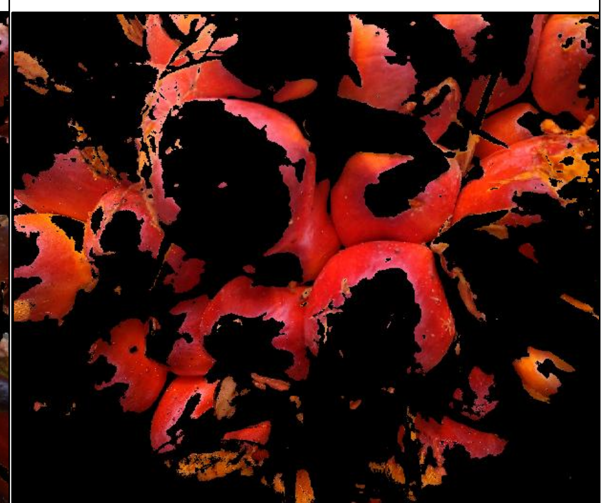
Original Image	**Spikes region of the image**
	
Maroon region of the image	**Red region of the image**
	

Image 1 – Under Ripe Category

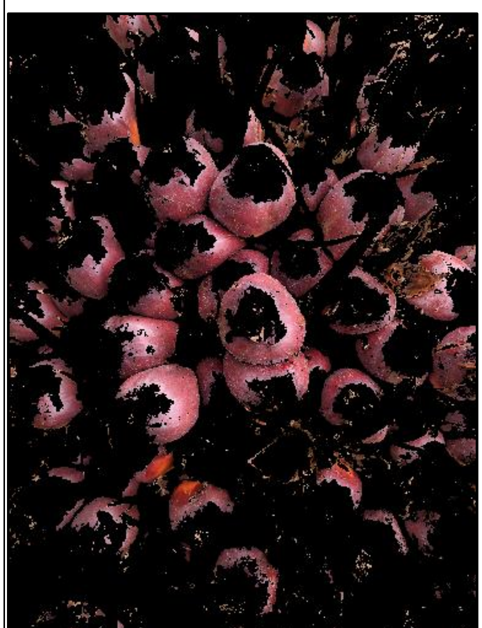
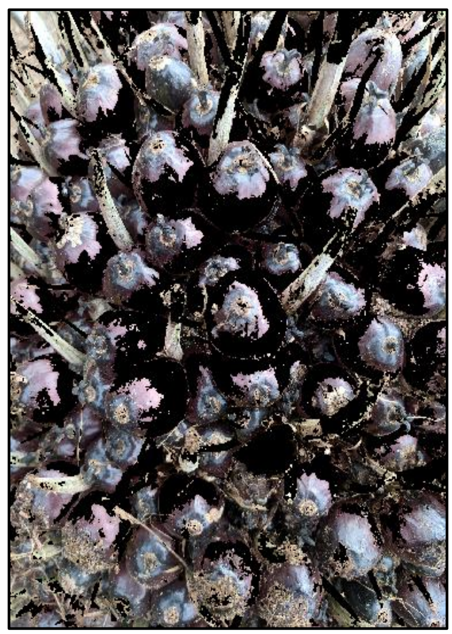
Original Image	**Spikes region of the image**
	
Maroon region of the image	**Blackish region of the image**
	

Image 2 – Under Ripe Category

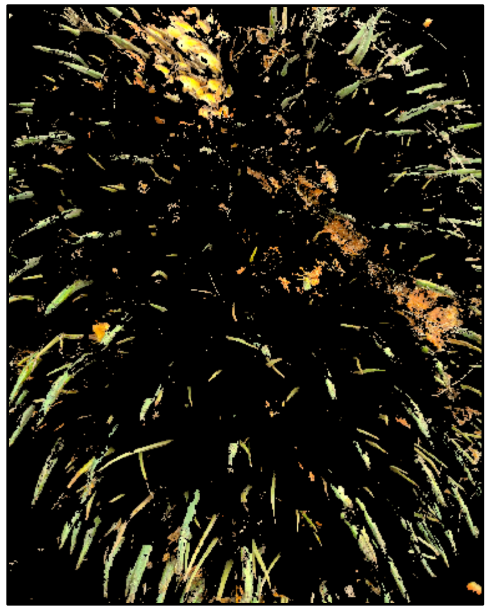
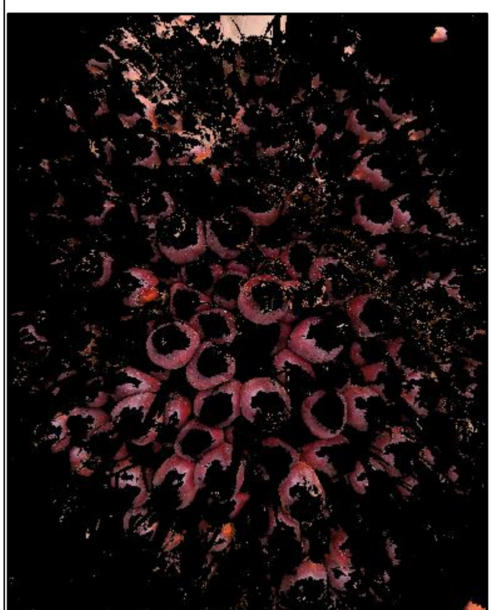
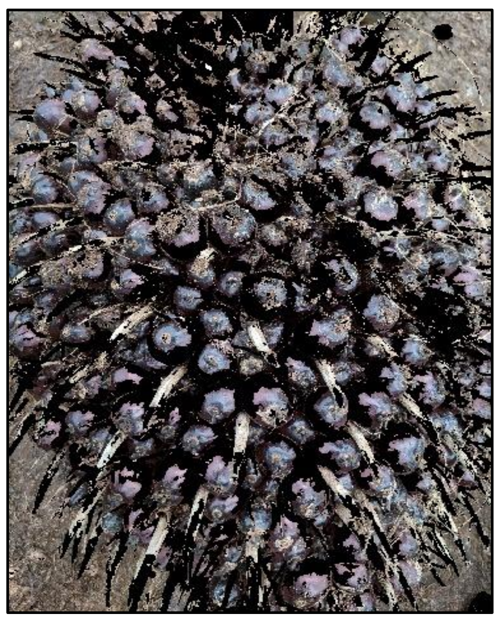
Original Image	**Spikes region of the image**
	
Maroon region of the image	**Blackish region of the image**
	

Image 1 – Over Ripe Category

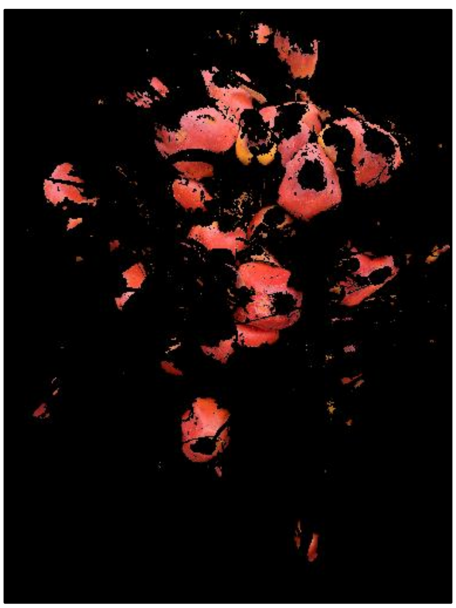
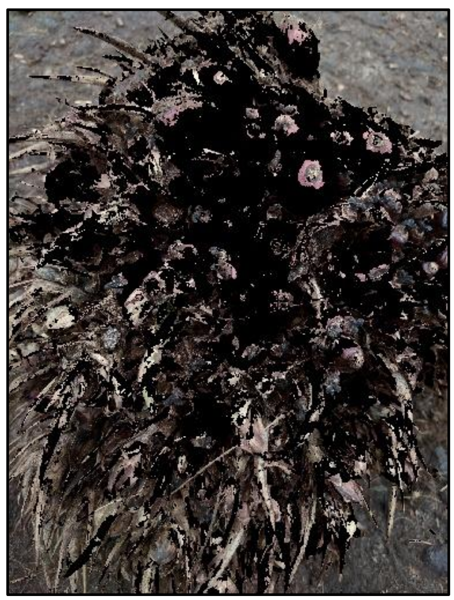
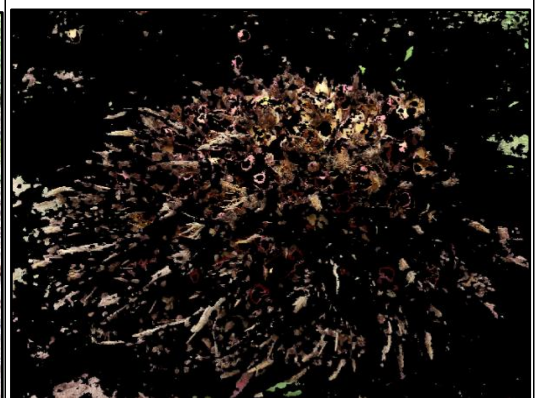
Original Image	**Spikes region of the image**
	
Red region of the image	**Blackish region of the image**
	

Image 2 – Over Ripe Category

Original Image	**Spikes region of the image**
	
Red region of the image	**Blackish region of the image**
	

Appendix B

Ripe category – Mean RGB values

Image	mean R	mean G	mean B	Image	mean R	mean G	mean B
RIPE1	94.9388	68.1665	54.6982	RIPE24	146.3316	80.8204	67.7184
RIPE2	126.3737	96.284	85.0583	RIPE25	160.6859	90.8658	62.6814
RIPE3	102.2471	74.1366	57.5037	RIPE26	107.3837	65.0475	53.7761
RIPE4	122.5981	74.4034	67.5984	RIPE27	110.8852	64.1295	48.1057
RIPE5	111.547	78.1723	61.8941	RIPE28	88.496	41.5179	20.8363
RIPE6	127.048	78.334	50.88	RIPE29	119.4839	66.9683	59.4132
RIPE7	119.172	60.6821	43.5258	RIPE30	139.7227	87.8384	67.6439
RIPE8	141.099	89.0765	68.539	RIPE31	139.716	69.9276	52.5128
RIPE9	104.5958	80.0019	70.7131	RIPE32	109.0254	65.773	51.2051
RIPE10	156.8402	84.9772	70.4315	RIPE33	100.8748	61.1828	40.909
RIPE11	113.9207	71.7813	64.9584	RIPE34	146.1799	107.5023	87.6413
RIPE12	104.304	62.4963	42.422	RIPE35	140.6923	81.7263	71.8477
RIPE13	106.3622	66.6595	60.0249	RIPE36	158.099	86.9204	76.2518
RIPE14	86.6106	53.7101	42.4549	RIPE37	120.8599	86.3806	75.897
RIPE15	108.5434	66.1185	48.4287	RIPE38	109.3157	79.5379	62.6159
RIPE16	123.7549	66.3474	45.0078	RIPE39	127.2038	97.0853	85.6426
RIPE17	126.1865	74.4357	38.8301	RIPE40	108.2189	61.6673	56.0156
RIPE18	107.4612	65.2697	47.7179	RIPE41	133.4242	76.0885	46.7632
RIPE19	140.3416	88.4106	67.9514	RIPE42	133.3225	90.9447	74.4651
RIPE20	115.2376	68.3533	56.224	RIPE43	109.4629	66.9463	49.119
RIPE21	153.9085	85.8495	80.2941	RIPE44	146.3316	80.8204	67.7184
RIPE22	106.3768	61.5381	50.9592	RIPE45	150.6115	90.1322	59.6511
RIPE23	148.1632	85.0851	61.7096				

Under Ripe category – Mean RGB values

Image	mean R	mean G	mean B	Image	mean R	mean G	mean B
UNDER-RIPE1	57.3522	46.6835	32.72	UNDER-RIPE24	92.9303	61.7369	57.5153
UNDER-RIPE2	89.8652	71.0092	51.8767	UNDER-RIPE25	84.2543	40.6321	25.7921
UNDER-RIPE3	63.9766	47.3666	49.6438	UNDER-RIPE26	48.5071	22.9014	17.0367
UNDER-RIPE4	43.3658	36.6637	36.0044	UNDER-RIPE27	44.9097	37.9311	37.5657
UNDER-RIPE5	82.6964	53.8669	53.6458	UNDER-RIPE28	78.1825	55.6218	54.3691
UNDER-RIPE6	54.9743	36.4851	32.3829	UNDER-RIPE29	95.3117	81.6034	79.7708
UNDER-RIPE7	93.1955	72.0801	67.7358	UNDER-RIPE30	54.3992	47.6213	46.9197
UNDER-RIPE8	87.3701	74.2174	69.5337	UNDER-RIPE31	97.9116	82.8147	78.9759
UNDER-RIPE9	40.0877	31.168	31.3663	UNDER-RIPE32	99.3374	74.6805	76.8019
UNDER-RIPE10	98.6457	83.8943	76.5285	UNDER-RIPE33	83.8188	67.6101	56.8233
UNDER-RIPE11	89.8799	54.5364	31.8396	UNDER-RIPE34	96.1841	81.1764	80.5838
UNDER-RIPE12	57.4004	40.4536	39.5496	UNDER-RIPE35	67.1667	38.154	27.8747
UNDER-RIPE13	60.634	36.3552	36.734	UNDER-RIPE36	102.4635	80.7329	56.5735
UNDER-RIPE14	79.6092	36.4591	36.4779	UNDER-RIPE37	94.9554	80.0931	77.2836
UNDER-RIPE15	91.068	76.5306	72.6017	UNDER-RIPE38	44.1218	37.6013	39.0793
UNDER-RIPE16	78.0543	39.0892	29.2474	UNDER-RIPE39	92.4942	74.4064	72.5105
UNDER-RIPE17	81.535	47.3329	34.3391	UNDER-RIPE40	88.2897	67.8016	59.5745
UNDER-RIPE18	97.5038	81.6554	78.5846	UNDER-RIPE41	54.0665	39.2234	38.7321
UNDER-RIPE19	95.4943	70.9374	65.3768	UNDER-RIPE42	73.6685	60.205	51.792
UNDER-RIPE20	73.3378	36.7186	27.4578	UNDER-RIPE43	92.0566	73.4054	64.7751
UNDER-RIPE21	105.7181	88.9611	82.3616	UNDER-RIPE44	81.542	41.0953	28.8177
UNDER-RIPE22	99.6142	81.5394	72.3217	UNDER-RIPE45	58.2206	39.3355	36.3134
UNDER-RIPE23	92.159	82.9459	75.3722				

Over Ripe category – Mean RGB values.

Image	**mean R**	**mean G**	**mean B**	**Image**	**mean R**	**mean G**	**mean B**
OVER-RIPE1	95.6221	68.7948	57.5228	OVER-RIPE24	60.0975	43.97	35.0857
OVER-RIPE2	89.0677	62.2503	50.8075	OVER-RIPE25	101.5778	73.7939	58.0371
OVER-RIPE3	57.9193	47.8231	40.8452	OVER-RIPE26	64.5127	56.4168	53.1609
OVER-RIPE4	49.8693	36.713	33.4869	OVER-RIPE27	53.5904	43.8387	38.7869
OVER-RIPE5	71.9003	45.7095	32.6494	OVER-RIPE28	68.552	57.208	52.5637
OVER-RIPE6	69.0048	58.4657	54.1101	OVER-RIPE29	60.3412	53.0355	48.5028
OVER-RIPE7	61.2567	49.3511	47.2504	OVER-RIPE30	63.3205	47.7067	37.6902
OVER-RIPE8	72.287	46.5085	32.8418	OVER-RIPE31	58.1083	49.7508	44.5845
OVER-RIPE9	67.6923	52.6231	48.3308	OVER-RIPE32	57.6693	51.6262	47.7986
OVER-RIPE10	64.9183	47.598	42.511	OVER-RIPE33	67.3563	56.6532	49.1903
OVER-RIPE11	88.2197	52.4329	45.1185	OVER-RIPE34	72.5675	64.3654	61.2304
OVER-RIPE12	61.7356	54.3788	52.9293	OVER-RIPE35	69.2378	58.5978	51.1512
OVER-RIPE13	97.803	88.2196	87.1471	OVER-RIPE36	78.6857	54.4613	41.2023
OVER-RIPE14	47.8699	24.2897	11.5989	OVER-RIPE37	76.0816	49.1919	35.3257
OVER-RIPE15	67.8587	51.9682	45.9405	OVER-RIPE38	76.9104	56.4549	45.0017
OVER-RIPE16	65.0691	37.7807	22.8919	OVER-RIPE39	111.8587	81.3945	62.4877
OVER-RIPE17	56.7032	37.9995	28.8096	OVER-RIPE40	73.7587	60.3789	51.6577
OVER-RIPE18	97.5385	76.0341	68.1281	OVER-RIPE41	67.5063	59.5478	56.4787
OVER-RIPE19	86.3386	67.4935	53.5492	OVER-RIPE42	100.21	70.2547	54.8701
OVER-RIPE20	72.0279	45.2832	31.8503	OVER-RIPE43	75.8389	63.0549	54.1588
OVER-RIPE21	77.9257	57.5693	46.1778	OVER-RIPE44	64.1123	47.3194	37.9484
OVER-RIPE22	49.5791	39.1552	32.7002	OVER-RIPE45	56.1902	47.689	42.1301
OVER-RIPE23	62.2189	50.5086	42.8763				

Appendix C

Under Ripe category – Area of biggest blob

Image	**Bunch Size**	**largest blob Size**	**blob%**	**Image**	**Bunch Size**	**largest blob size**	**blob%**
UNDER-RIPE1	71232	59428	83.4288	UNDER-RIPE24	87407	58626	67.07243
UNDER-RIPE2	282360	195134	69.10823	UNDER-RIPE25	4279593	4180383	97.68179
UNDER-RIPE3	9697454	9685532	99.87706	UNDER-RIPE26	4919351	3598682	73.15359
UNDER-RIPE4	7038984	6952855	98.7764	UNDER-RIPE27	5781664	3409851	58.97698
UNDER-RIPE5	185929	30275	16.2831	UNDER-RIPE28	264852	223205	84.27537
UNDER-RIPE6	105810	66779	63.11218	UNDER-RIPE29	10797582	5679887	52.60332
UNDER-RIPE7	9309027	8956581	96.21393	UNDER-RIPE30	7033146	3884278	55.22817
UNDER-RIPE8	9240664	8481716	91.78687	UNDER-RIPE31	11055045	7545139	68.25064
UNDER-RIPE9	6602437	4608863	69.80548	UNDER-RIPE32	11076533	6637278	59.92198
UNDER-RIPE10	8823005	8683105	98.41437	UNDER-RIPE33	11021709	6593067	59.81892
UNDER-RIPE11	264213	253127	95.80414	UNDER-RIPE34	10902320	7429000	68.14146
UNDER-RIPE12	6144916	3395967	55.26466	UNDER-RIPE35	6168404	2849942	46.20226
UNDER-RIPE13	63533	52666	82.8955	UNDER-RIPE36	39733	5338	13.43468
UNDER-RIPE14	290446	258479	88.99382	UNDER-RIPE37	9413036	5083612	54.00608
UNDER-RIPE15	10859556	3490007	32.13766	UNDER-RIPE38	5537650	2903764	52.43676
UNDER-RIPE16	4544189	2441148	53.72021	UNDER-RIPE39	11004976	1653466	15.02471
UNDER-RIPE17	658425	422988	64.2424	UNDER-RIPE40	8726120	7993196	91.6008
UNDER-RIPE18	8520813	6391261	75.00764	UNDER-RIPE41	20275	14973	73.84957
UNDER-RIPE19	11991363	6285647	52.41812	UNDER-RIPE42	649297	111768	17.21369
UNDER-RIPE20	4574099	2307751	50.45258	UNDER-RIPE43	170947	96557	56.48359
UNDER-RIPE21	10050528	5343083	53.16221	UNDER-RIPE44	67075	36539	54.47484
UNDER-RIPE22	11286904	8532161	75.59346	UNDER-RIPE45	29249	21741	74.33075
UNDER-RIPE23	61643	42547	69.02162				

Over Ripe category – Area of biggest blob

Image	**Bunch Size**	**largest blob size**	**blob%**	**Image**	**Bunch Size**	**largest blob size**	**blob%**
OVER-RIPE1	9938028	4861003	**48.91315**	OVER-RIPE24	5847744	296797	**5.07541**
OVER-RIPE2	9905374	4079377	**41.18347**	OVER-RIPE25	11514736	2996292	**26.02137**
OVER-RIPE3	9302509	2641869	**28.39953**	OVER-RIPE26	6630113	3297878	**49.7409**
OVER-RIPE4	6765806	2337760	**34.55257**	OVER-RIPE27	5802944	3087011	**53.19733**
OVER-RIPE5	56023	23466	**41.88637**	OVER-RIPE28	5215513	1462306	**28.03763**
OVER-RIPE6	5560831	2286199	**41.11254**	OVER-RIPE29	9763574	3643118	**37.31336**
OVER-RIPE7	4518617	823238	**18.2188**	OVER-RIPE30	5768706	3179813	**55.12177**
OVER-RIPE8	42681	19725	**46.21494**	OVER-RIPE31	8310905	2678889	**32.23342**
OVER-RIPE9	5476389	2199840	**40.16954**	OVER-RIPE32	9908148	3736993	**37.71636**
OVER-RIPE10	4274851	2080996	**48.67997**	OVER-RIPE33	8631096	2446945	**28.35034**
OVER-RIPE11	8927041	3962365	**44.3861**	OVER-RIPE34	7188009	2997263	**41.6981**
OVER-RIPE12	10503801	3677497	**35.01111**	OVER-RIPE35	8765673	2380155	**27.15313**
OVER-RIPE13	12027209	2935606	**24.40804**	OVER-RIPE36	11234288	1014255	**9.028209**
OVER-RIPE14	166362	69025	**41.49085**	OVER-RIPE37	8461634	1769452	**20.91147**
OVER-RIPE15	9027955	3684485	**40.81196**	OVER-RIPE38	5664338	1198786	**21.16374**
OVER-RIPE16	38947	28389	**72.89137**	OVER-RIPE39	11631399	1680506	**14.44801**
OVER-RIPE17	8032999	9628	**0.119856**	OVER-RIPE40	6512003	1680506	**25.80628**
OVER-RIPE18	11951749	5472291	**45.78653**	OVER-RIPE41	6960937	2918629	**41.92868**
OVER-RIPE19	10396991	5186946	**49.88891**	OVER-RIPE42	4071557	142427	**3.498097**
OVER-RIPE20	9863948	4355582	**44.15658**	OVER-RIPE43	8990928	4324692	**48.10062**
OVER-RIPE21	5829424	974111	**16.71024**	OVER-RIPE44	5694359	280577	**4.92728**
OVER-RIPE22	6230981	1074078	**17.2377**	OVER-RIPE45	5890761	2865333	**48.64113**
OVER-RIPE23	5991177	965179	**16.11001**				