Development of Ripeness Indicator for Quality Assessment of *Harumanis* Mango by using Image Processing Technique

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Abstract. Visual appearance is the main source of information that can be used for quality assessment of mango. In this study, a non-destructive ripeness level estimation for mango of the cultivar Harumanis based on digital image analysis was employed. The changing peel and flesh colour of mango is strongly correlated to ripeness that can be measured as a sensual quality parameter. This measurement of ripeness level has been determined by image analysis technique which needs to attribute external and internal colour feature from image segmentation. Multilevel thresholding technique is proposed for colour image segmentation to extract the mango region from the background which every channel of five colour spaces have been applied. Colour analysis technique and Total soluble solids (TSS) is used to compare and evaluate for the prediction. The optimal results were obtained that a* channel from L*a*b colour space has given more logical and better performance of prediction which is more than 92% accuracy.

Keywords—Image Processing, Quality Assessment, Ripeness Indicator, *Harumanis* Mango.

1. Introduction

Mango is one of the climacteric fruits which can ripen after being picked and the peel colour will keep on changing during the ripeness level/process. Naturally, the changing of skin colour occurs from dark green at the initial level, and then to green-yellowish at the final level of ripening. The peel colour becomes the main parameter of the quality and also a dominant attribute in consumer acceptance [2]. Therefore, the ripening level of the mango is an important factor for determining the optimal post-harvest strategies for handling and marketing [3]. The changing of peel colour can be measured by using the image processing technique. *Harumanis* is the most important mango crop of Perlis, Malaysia and its annual production has exceeded worldwide [1]. For effective postharvest handling and to control the quality of *Harumanis*, an effective technique of commercial fruit pack houses and processing industries are needed to classify the ripening level of the fruit.

Recently, digital image processing has become a powerful tool for the characterization and quality assessment of fruits. The quality of fruits is an important field in the food industry which generally can be
defined as a degree of excellence, a high standard or value [4]. The quality of mango which is typically perceived from consumers is mostly based on colour (appearance), and then the aroma (flavour), the firmness (texture) and the nutritive value [4]. Most consumers normally regarded the colour as the main indicator to determine the appearance of a fruit [5]. Most of the vision systems that have been used in the grading applications were using colour mapping to evaluate the quality of fruits [6]. [7] has used this technique to perform three-dimensional RGB colour space to determine the quality of date and tomato. [8] has used RGB images to classify the degree of browning in mango and date skin into three categories. However, the quality assessment using these attributes involving image processing techniques is typically a complex process [9].

This paper presents the evaluation of colour analysis of *Harumanis* mango. The technique will establish relationships between peel colour measurements and major physiological quality attributes which relates to the ripeness level of *Harumanis* mango. In this work, a comparative study among five different colour spaces (*RGB*, *HSV*, *YCrCb*, *L*·*a*·*b*· and *YUV*) was presented to improve the existing technique for the conversion of RGB colour units to L·a·b· colour space [10]. These fifteen colour channels were analysed separately and the colour histograms of individual channels was generated to analyze the relationship of colour changing. The chemical parameters such as soluble solids content (TSS) had been used to validate the prediction result of ripening stage with image processing. Appropriate models for each colour were determined based on results of the statistical analysis.

2. Image Processing Technique

Image processing technique data analysis is shown in Figure 1. Image segmentation is one of the most important steps before colour analysis and further evaluation can be performed. It is a process to divide an image into significant regions or segments and extract out the interested target [10-13]. In other words, the region of the fruit must be separated from the background. In this study, a hybrid technique for image segmentation based on colour threshold and edge detection method is proposed. The threshold method is a process to eliminate a region in the image frame for foreground detection [14-15]. This process basically replaces each pixel in an image with a black/white pixel if the image intensity is less/greater than threshold range. The general rule for gray image thresholding is shown in equation (1) as:

\[
T_h = \begin{cases} 
0, & \text{if } f(x,y) < T_1 \\ 1, & \text{if } T_1 \leq f(x,y) \leq T_2 \\ 0, & \text{if } f(x,y) > T_2 
\end{cases} 
\]

where \( f(x,y) \) is the original pixel value, \( x \) and \( y \) are the size of image frame in x-axis and y-axis, respectively, \( T_h \) is the result of pixel value after thresholding, \( T_1 \) and \( T_2 \) are the lower and upper value of threshold range respectively. 0 and 1 are the output values which represent the result in a binary image as black (background) and white (foreground), respectively. The ranges of threshold values are chosen from the lower and upper of the image histogram.

The captured RGB image of mango is not uniformly distributed, so that a single channel process of thresholding is not efficient [16]. Therefore, multi-level colour thresholding based on pixel-based segmentation techniques for colour image should be used. The RGB image is firstly split into three single channels of red, green and blue, respectively. Then, the thresholding is used for every channel to create binary mask image of red mask, \( m_r(x,y) \), green mask, \( m_g(x,y) \) and blue mask \( m_b(x,y) \) as shown in equations below:
where \( f_r(x, y) \), \( f_g(x, y) \), and \( f_b(x, y) \) is a red, green and blue image channel, respectively. \( T_{lr} \), \( T_{lg} \) and \( T_{lb} \) are lower threshold value for red, green and blue channel respectively. \( T_{ur} \), \( T_{ug} \) and \( T_{ub} \) are the upper threshold value for red, green and blue channels respectively.

The three binary masks for each channel are then merged using a bitwise-AND operator to create a new combined mask image \( M(x, y) \) as shown in equation (5). The bitwise-AND operator compares each bit of its first operand to the corresponding bit of its second operand. If both bits are 1, the corresponding result bit is set to 1. Otherwise, the corresponding result bit is set to 0 [17].

\[
M(x, y) = m_r(x, y) \land m_g(x, y) \land m_b(x, y)
\]  

3. Methodology

The system was configured as shown in Figure 2a. The digital camera used for colour image acquisition is Basler acA1600-60gc GigE with the e2v EV76C570 CMOS sensor delivers 60 frames per second at 2 MP resolution and capture images of 1600x1200-pixel resolution. This camera is mounted 400mm on top of the chamber which illumination system provides two 10-Watt LED powered by direct current (12 V). This camera is equipped with a Computer C-mount lens with a fixed focal length of 8 mm and an aperture range from F1.4 - F16. The camera was connected to a computer via Gigabit Ethernet (GigE). This interface is used because of its high-performance for industrial cameras that can provide a framework for high-speed transmitting data over Ethernet networks [11]. The inner background colour of the chamber had a rough texture to minimize the directional reflections that can be caused by the bright spots and was painted with plain white to maximize its reflectivity so that it can provide homogeneous light. The light intensity inside the chamber was kept at 120 lux, measured by digital lux meter. The image frames per second are captured and digitized into 24-bit RGB data, with 8 bits for each colour channel. Two images per mango (side A and B) were captured for external inspection. Some of the fruits were selected randomly for internal inspection where the mango is sliced in half (side C and D) as shown in Figure 2b also captured. The captured images are stored in computer memory for processing.

To predict the quality of *Harumanis* mango, a dataset was made to classify the ripening level obtained from 247 selected mangoes. Then the farmer will classify all the mangoes into four ripening levels manually based on the peel colour visual assessment. Out of 247 recorded observations, 24, 68, 87 and 68 were classified under M1, M2, M3 and M4 respectively. To validate this sorting, the internal colour of the slice in half and peel colour of mango and the total soluble solids (TSS) were determined in the laboratory. Five colour spaces have been applied to analyze the changing in colour during ripening of *Harumanis* mango.

The image analysis for different colour spaces is needed in order to carry out a successful prediction and classification of ripening level. In addition, the processing computational cost for different algorithms according to the colour space can also be observed [18]. In this work, the consideration of these aspects is important to choose the best colour space to make sure the image processing is successful. The internal of the slice in half and peel colour of mango was measured with the industrial digital camera from Basler and through proposed image processing technique. The raw RGB image format captured from camera was converted into five different colour spaces such as RGB, HSV, YCrCb, Lab, and YUV by using a
The system setup. Figure 2b. The example of the captured sample for both external side A and B (from left top) and internal side C and D (from left bottom) view.

The TSS or Degrees Brix (°Brix) was measured with a refractometer which refers to the total amount of sugar constituents of the juice [19]. This instrument has a range of 0 to 30°Brix and resolutions of 0.1. The sample was selected randomly to extract mango juice that can be used to determine TSS by placing 1 to 2 drops of clear juice on the prism of the refractometer. This measurement was repeated twice for every sample where the prism of the refractometer was washed with distilled water and dried with a tissue paper before the next reading is done.

Unfortunately, even though the boundary has been nicely extracted, sometimes the interior of the mango mask image and the background has the same intensities due to the light conditions inside the chamber. It has caused the thresholding operation cannot distinguish the mango mask image from the background, resulting in a hole inside the boundary mask image. To solve this problem, a flood fill algorithm is used by combining the mask and inverted mask image together. Inverted mask image means the colour black of mask image becomes white and white becomes black. This combination can be performed by using bitwise OR operation to obtain the final foreground mask with holes filled in to get the new mask image. Figure 3 shows the new segmented mask image of mango with the solid white colour after flood fill algorithm is applied.

Figure 3: Solid mask image. (from left: original image, binary image and mask image).
4. Results and Discussion

4.1 Colour Image Analysis

Five colour spaces were analyzed to evaluate changes in peel (external) and flesh (internal) colour of mango between artificial ripening stages by measuring the average intensity value (mean) as shown in Figure 4a-j. The mean intensity value of colour images can be measured separately from histograms of individual channels. Generally, peel colour will change from dark green (M1) to yellow (M4) after harvesting [20]. While the flesh colour will change from whitish green (M1) to cream (M2) and then to various shades of bright yellow (M3) and finally to yellow/orange in fully ripe (M4). There was a gradual increase in peel colour of channel \( Cr \) (Figure 4e), \( a^* \), \( b^* \) (Figure 4g) and \( U \) (Figure 4i) while the channels \( Red \) (Figure 4a), \( Cb \) (Figure 4e) and \( Y_{VP} \) (Figure 4i) showed degradation. The gradual and substantial change in colour during the entire fruit ripening period for these channels should be considered for a better discrimination. The other channels showed the fluctuations or no significant changes. Therefore, these channels were considered to be less important to discriminate between ripening levels.

![Colour Image Analysis Graphs](image-url)
4.2 Correlations Between Colour and Physicochemical Analysis

Total soluble solids (TSS) content has shown the expected trends during the ripening period. TSS is selected as physicochemical properties to compare the prediction result of ripening level with the image processing method. Generally, the average values of TSS score is lower on unripe (M1) level and it will significantly increase during the ripening period as shown in observation result of Table 1. Table 2 shows the mean pixel value for every channel of five colour spaces comparing the value of TSS for cross validation to represent the ripeness levels of *Harumanis*. From this observation, it shows that there is a slight increment of the pixel value for *a*, *b*, U and Cr channels but a decrease for Red, Cb and Vuv channels. These channels should be used for further analysis to estimate the ripeness level of *Harumanis*. The other channels were less important because there were no significant changes in pixel value.

The classification accuracy is obtained by using fuzzy logic algorithm-based system for the seven selected colour channels and the average classification accuracy by the expert. By observing the results in Table 3, it clearly shows that a* channel had exhibited more effective results with a very high accuracy of
more than 92% and followed by Red, Vyuv, and Cb with a minimum accuracy of more than 85%, 83%, 82%, respectively. The other colour channel shows a slightly low result due to the low correlation between ripeness levels.

Table 1. Linearly increasing of TSS during ripening

| Ripeness Level | TSS |
|----------------|-----|
| M1             | 5.6 |
| M2             | 8.4 |
| M3             | 10.5|
| M4             | 16.8|

Table 2. Harumanis ripeness indicators and quality parameters evaluated on fruits harvested in different ripeness levels established visually by the skin colour of M1, M2, M3 and M4 and Brix Index.

| Brix (%) | RGB  | HSV  | YCrCb  | L*a*b  | YUV  |
|----------|------|------|--------|--------|------|
| 5.1-10   | Blue | Gree | Red    | Hue    | Val  | Y    | Cr    | Cb    | L    | *a  | *b  | Vyuv | U    | Vyuv |
| <5       | 113.2| 113.7| 100.5  | 89.4  | 122.2| 114.9| 111.1| 122.2| 107.2| 114.0| 117.8| 144.3| 109.3| 124.7|
| 10.1-15  | 111.5| 111.0| 106.3  | 92.34 | 124.9| 115.9| 111.0| 127.0| 101.8| 116.1| 120.5| 149.1| 108.0| 130.3|
| 15.1>    | 113.8| 112.4| 126.6  | 96.13 | 102.4| 124.9| 115.9| 127.0| 101.8| 116.1| 120.5| 149.1| 108.0| 130.3|

Table 3. The performance analysis of proposed method

| Ripeness Level | Accuracy (%) |
|----------------|--------------|
|                | *a  | *b  | U   | Cr  | Red | Cb  | Vyuv |
| M1             | 92   | 77  | 83  | 78  | 86  | 82  | 84   |
| M2             | 95   | 82  | 74  | 80  | 85  | 84  | 82   |
| M3             | 97   | 91  | 87  | 85  | 89  | 91  | 88   |
| M4             | 97   | 93  | 86  | 88  | 93  | 91  | 90   |

5. Conclusion

The quality assessment of fruits is normally done manually by experts. However, it is very subjective because the individual assessments have shown different results. This study was conducted to find out the best suitable colour channel to predict the ripeness level of Harumanis. Five colour spaces are used, and the features extracted from every channel were analyzed with discriminant analysis. The ripeness level of Harumanis was classified using hierarchical cluster analysis based on changes that occurred in peel colour and the result was compared with the physicochemical test. Improved analytical methods by combining the inputs from a more comparative study on the extracted features into algorithms classification will be applied in the future work.

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