

Assessment of banana fruit maturity by image processing technique

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Abstract Maturity stage of fresh banana fruit is an important factor that affects the fruit quality during ripening and marketability after ripening. The ability to identify maturity of fresh banana fruit will be a great support for farmers to optimize harvesting phase which helps to avoid harvesting either under-matured or over-matured banana. This study attempted to use image processing technique to detect the maturity stage of fresh banana fruit by its color and size value of their images precisely. A total of 120 images comprising 40 images from each stage such as under-mature, mature and over-mature were used for developing algorithm and accuracy prediction. The mean color intensity from histogram; area, perimeter, major axis length and minor axis length from the size values, were extracted from the calibration images. Analysis of variance between each maturity stage on these features indicated that the mean color intensity and area features were more significant in predicting the maturity of banana fruit. Hence, two classifier algorithms namely, mean color intensity algorithm and area algorithm were developed and their accuracy on maturity detection was assessed. The mean color intensity algorithm showed 99.1 % accuracy in classifying the banana fruit maturity. The area algorithm classified the under-mature fruit at 85 % accuracy. Hence the maturity assessment technique proposed in this paper could be used commercially to develop a field based complete automatic detection system to take decision on the right time of harvest by the banana growers.

Keywords Banana · Fruit maturity detection · Image analysis · Non-destructive quality assessment

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Introduction

Banana is a globally consumed fruit and the fourth most important food crop along with rice, wheat and maize in the world. It provides livelihood and nutritional security to millions of people across the globe. Banana is grown in 150 countries across the world in an area of 4.84 million ha producing 95.5 million tons of fruit (Singh 2010). India, Brazil, Philippines, Indonesia, China, Ecuador, Cameroon, Mexico, Columbia and Costa-Rica are the major countries that grow and produce banana primarily. However, the order of major banana exporters in the world are Ecuador, Costa Rica, Philippines, Columbia, Guatemala, Belgium, USA, Honduras, Thailand, Panama, Cameroon, Germany, Brazil, France, China and Spain. This contradictory in production and export of banana fruit among these countries are mainly due to the perishable nature of banana and lack of knowledge and technical know-how of fruit quality standard to match the international standard (Patil and Rawale 2012). Maturity of the banana bunches dictate the quality of fruit during ripening and overall marketability. Major post harvest loss could be managed by harvesting the fruit at proper maturity stage (Chegeh et al. 1995). Early harvest of banana may lack flavour and may not ripe properly, while harvesting it late may over ripe the fruit and cause splitting (Patil and Rawale 2012). Banana is harvested at over mature stage for local market distribution than those which are meant for export. Hence, it is important to harvest fruit at the right maturity stage to suit the purpose. Maturity of the fruit is assessed by measures such as change of peel color from dark green to pale green, disappearance of angularity, finger length and diameter. Based on these maturity indices, the banana bunches can be classified into three categories viz., un-mature, mature and over-mature fruit (Muchui et al. 2010). The mature fruit with pale green color with disappeared angularity having 34–35 mm finger diameter and 21–22 cm finger length are the primary

requirements for exporting banana. Conventional method of assessing the maturity was done by trained personnel through manual vision for assessing color/angularity. The hand-calipers and scales are also used to assess optimum finger diameter and length. The manual sorting of banana fruit bunches is a time consuming, labour-intensive process resulting in bias and human error, which drastically affects the growers profitability. Hence there is an urgent need for a reliable, rapid and accurate automatic detection technique for assessing the banana fruit maturity.

Automatic detection system, based on camera with computer based technology has been widely explored for the quality analysis and grading of agricultural products in recent years. This is known as computer vision system or computerised image analysis technique and it has proven to be successful for objective measurement of various fruit crops (Bato et al. 2000; Riyadi et al. 2007; Roseleena et al. 2011; Rodriguez-Pulido et al. 2012). This system basically consists of standard illumination, a digital camera for image capturing and computer software for image processing (Mendoza and Aguilera 2004). Image processing is an innovative field of science where the acquired image is transformed into useful information. In recent years, image processing has become an incredible part in various disciplines like medical, communication, geographical information system and so on. However in agriculture, image processing is in its initial (progress) stage of practical application. The image processing has been now widely suggested to assess the quality of fruit from the images (Quevedo et al. 2008). This has been possible because the image texture reflects the changes in intensity value, which might contain information about the color and the physical structure of the objects. Molto et al. (1992) first used a vision system to count the number of ripe and unripe citrus fruit on a tree through image analysis prior to harvesting. Subsequently this technology has been investigated in strawberry (Bato et al. 2000), papaya (Riyadi et al. 2007), grape (Rodriguez-Pulido et al. 2012) and oil palm (Roseleena et al. 2011) to sort matured fruit and achieved accuracy of 80–100 %.

Banana for export market are harvested at a light green mature stage and ripened artificially in ripening chambers. During ripening process, the banana peel color changes from green to yellow. Color of the peel is considered as a first quality parameter evaluated by traders and consumers using 7 point scale (scale 1 – green; scale 2 – green with, traces of yellow; scale 3 – more green than yellow; scale 4 – more yellow than green; scale 5 – green tip and yellow; scale 6 – all yellow; and scale 7 – yellow, flecked with brown). Application of image processing in banana started with Mendoza and Aguilera (2004) who implemented a computer vision system to identify the seven ripening stages of banana based on color, development of brown spots and image texture information with an accuracy of 98 %. Ripeness of banana, especially the

dark spotting in full ripped banana, could also be assessed from images by fractal texture Fourier analysis (Quevedo et al. 2008). These studies have illustrated the potential of using image processing in banana fruit quality analysis after harvest at trader and consumer level. However, the physiological maturity stages of banana using 3 point scale before harvest is also an important criteria of banana fruit quality assessment. Banana fruits harvested at correct physiological maturity stage can only give quality fruits after treatment in ripening chambers. Under-mature fruits could not produce characteristic flavour and color whereas over-mature fruits cause splitting and spoilage. Hence the non-destructive techniques to assess physiological maturity of banana using 3 point scale before harvest is as much important as that of the assessment of ripening stages of banana using 7 point scale after harvest. But still banana fruit maturity detection technique at farm before harvest has not yet been investigated. If we establish this system, it can provide several benefits such as (i) detection of under-mature fresh fruit bunches can prevent early harvesting, thereby allowing the bunches to mature in the plant, (ii) rapid detection to enable saving time and money, (iii) avoiding unwanted transportation of under-mature or over mature fruit to the ripening chambers. Hence, the present work aimed to develop image processing algorithms for the detection of banana fruit maturity.

Materials and methods

The maturity classification algorithm based on color and size were developed using image processing methods. Sample collection and image acquisition were primary tasks in the process of determining maturity of banana. Images of the collected samples were captured through the standard illumination and focus. Image processing toolbox of matlab 7.10 was used to manipulate captured images. Modules in the determination of maturity of banana are discussed in this section.

Sample collection

The study was conducted in Banana cv. Grand Naine. Based on the standards established by Muchui et al. (2010), the banana fresh fruit bunches can be broadly classified into three main categories namely: (a) ‘under-mature’ with the age of < 12 weeks after flowering characterised by dark green color with <34 mm finger diameter and 21 cm finger length (b) ‘mature’ with the age of 12–17 weeks after flowering characterised by pale green color with 34–35 mm finger diameter and 21–22 cm finger length and (c) ‘over-mature’ with the age of <17 weeks after flowering characterised by yellowish green color with >35 mm finger diameter and 22 cm finger length. Samples were collected from farmer’s

field at Sirumugai village, Coimbatore District, Tamil Nadu, India and at Erasakkanayakanur village, Theni District, Tamil Nadu, India. Twelve plants from each place were tagged and labelled with date of flower emergence to assess the maturity precisely. Four randomly selected bunches were harvested at under-mature, mature and over-mature stages by the skilled persons engaged specifically for maturity prediction and harvesting (representative sample from each class is shown in Fig. 1). Ten banana fingers were randomly collected from second and third hand of each bunch. Finally, total of 40 fingers were collected for each maturity category.

Image acquisition

Banana samples were placed on the table covered with a non-reflecting white cloth as a background of the image. The digital camera used for image acquisition was Olympus SP-510 UZ. Fruit samples were uniformly illuminated as per Mendoza and Aguilera (2004) with slight modifications. Four fluorescent lamps (Make - Philips; Model - TL-D Deluxe; Type - Natural daylight; Power - 18 W/965; Color temperature - 6500 K; Color rendering index (Ra) - 95 %), covered with light diffusers and arranged in the form of the square, were fit at 40 cm above the samples with 45° angle. Camera was located vertically over the fruit samples at a distance of 30 cm. The calibrated camera settings for this experiment were; ISO Sensitivity - 200; Shutter speed - 1/125; Aperture - 3.5; Resolution - 3072×2304; and Format - JPEG. A total of 120 images comprising of 40 images from each maturity category were obtained for analysis. Twenty of these images from each category in total of 60 images were selected as calibration images (CI) which were used to develop the algorithm and remaining twenty each were selected as validation images (VI).



Fig. 1 (a) under-mature, (b) mature, and (c) over-mature banana fresh fruits

Algorithm for maturity classification

The maturity of the banana fruit was determined primarily by the color and size values extracted from the image. Hence the algorithm for feature extraction from color and size was developed to classify the maturity stages. The steps involved in the development of the algorithm are presented in Fig. 2.

Background removal

Background was removed from the image using a threshold value and converted the RGB image into binary image. The converted binary image had 0's in the banana region and 1's in the background region as in Fig. 3. All banana images of different maturity stages were thresholded and segmented using the same procedure.

Extracting banana region

The binary image was converted into its complement image with 1's in the banana region and 0's in the background.

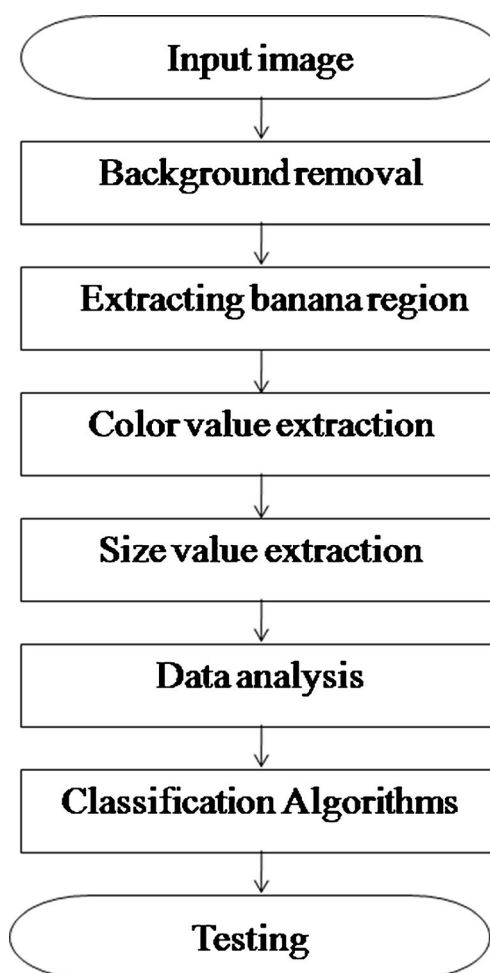


Fig. 2 Steps involved in the development of banana fruit maturity classification algorithm

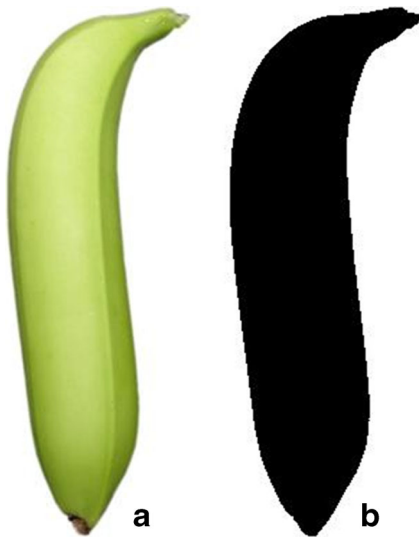


Fig. 3 (a) Original image, (b) Binary image of (a)

Complement image was used to identify the boundary of banana region. Positional coordinate values of the boundary region were stored in an array. The row and column coordinate values from an array were stored separately in two vectors which were used as vertices to select the polygon region of interest. Mask of the banana region was obtained using these polygon vertices (Gonzalez and Woods 2008) which also contains 1's in the banana region and 0's in the background as in Fig. 4a. This mask was multiplied with each color component (red, green and blue) of the original banana input image and these individual color components were concatenated together to extract the banana region from the original input image as in Fig. 4b.



Fig. 4 (a) The binary mask, (b) The extracted banana region

Color value extraction

Primary feature for classification of maturity level of banana was the color. The captured image was in RGB color model. Hence the RGB intensity color distribution in the banana was calculated using statistical moments obtained from histogram. Histogram for the banana region was computed using the vertices that were stored in the vectors (Gonzalez and Woods 2008). Horizontal axis of the histogram represents the intensity scale ranging from 0 to 255. The vertical scale of the histogram represents the frequencies of the pixel distribution. The histogram measures the pixels distribution in the intensity scale of 0 to 255. The central moment μ' has been calculated which provides quantitative information about the shape of histogram as pixel distribution. Central moments also referred as moments about the mean has been calculated as,

$$\mu_m = \sum_{n=0}^{L-1} ((X_n - y)^m t(X_n)) \quad (1)$$

where 'm' is an order of the moment, 'L' is the number of possible intensity values, ' x_n ' is the discrete variable represents intensity level in an image and 'y' is the mean. $t(x_n)$ is the probability estimation of occurrence of ' x_n '.

Mean can be defined as,

$$y = \sum_{n=0}^{L-1} (x_n t(x_n)) \quad (2)$$

From Eqs. (1) and (2), the moment for order '0' was always '1' and the moment for order '1' was always '0'. Hence these moments were ignored. The mean was considered as first order moment followed by variance, skewness and kurtosis as the second, third and fourth moment. Mean in the first order central moment was used to measure the average intensity value of the pixel distribution. The mean helps to identify the average color value of the pixels in an image.

Variance (μ_2) was used to measure how wide the pixels spread over from the mean value.

$$\mu_2 = \sum_{n=0}^{L-1} ((x_n - y)^2 t(x_n)) \quad (3)$$

The smoothness texture for an image was measured using variance. Image with constant intensity had a smoothness of '0' and the image with irregular intensity had a smoothness of '1'. In general, the smoothness of an image lies within '0' to '1'. Smoothness texture 'R' can be defined as,

$$R = (1 - (1 / (1 + \mu_2(x)))) \quad (4)$$

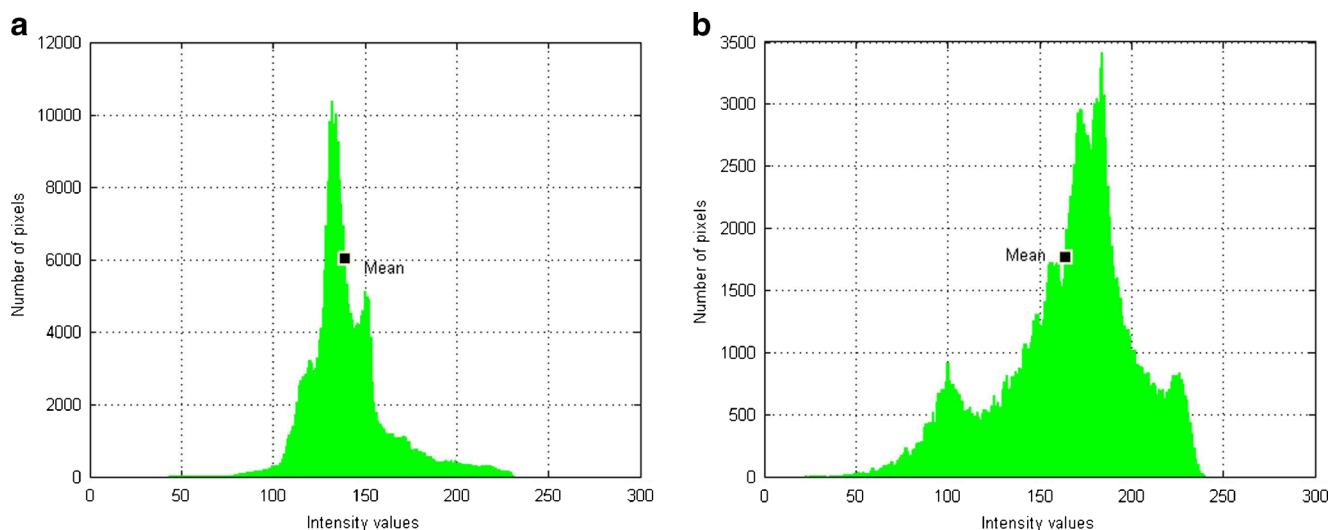


Fig. 5 (a) Positive skewness and (b) Negative skewness distribution

where ' μ_2 ' is the variance and ' x ' is an intensity level.

Skewness (μ_3) was used to measure asymmetric shape of the distribution. This shape distribution was either positively or negatively skewed. The distribution positively skewed denotes left side of the mean had more pixel values clustered but the tail extends towards the right side of the mean as in Fig. 5a. Similarly distribution negatively skewed denotes right side of the mean had more pixel values clustered but the tail extends towards the left side of the mean as in Fig. 5b.

$$\mu_3 = \sum_{n=0}^{L-1} ((x_n - y)^3 t(x_n)) \quad (5)$$

Kurtosis (μ_4) was used to measure the peakedness of the distribution. The distribution of the shape was either positive

or negative. Kurtosis with positive value was referred as leptokurtic. It had higher peaks around the mean with heavy tails as in Fig. 6a. Kurtosis with negative value was referred as platykurtic. It had flatter peaks around the mean with thinner tails as in Fig. 6b.

$$\mu_4 = \sum_{n=0}^{L-1} ((x_n - y)^4 t(x_n)) \quad (6)$$

Size value extraction

Size of banana was the second important feature in determining maturity level of banana. The area and perimeter of the fruit was generally used to represent their size feature. Area of the fruit was measured using total number of pixels in the fruit

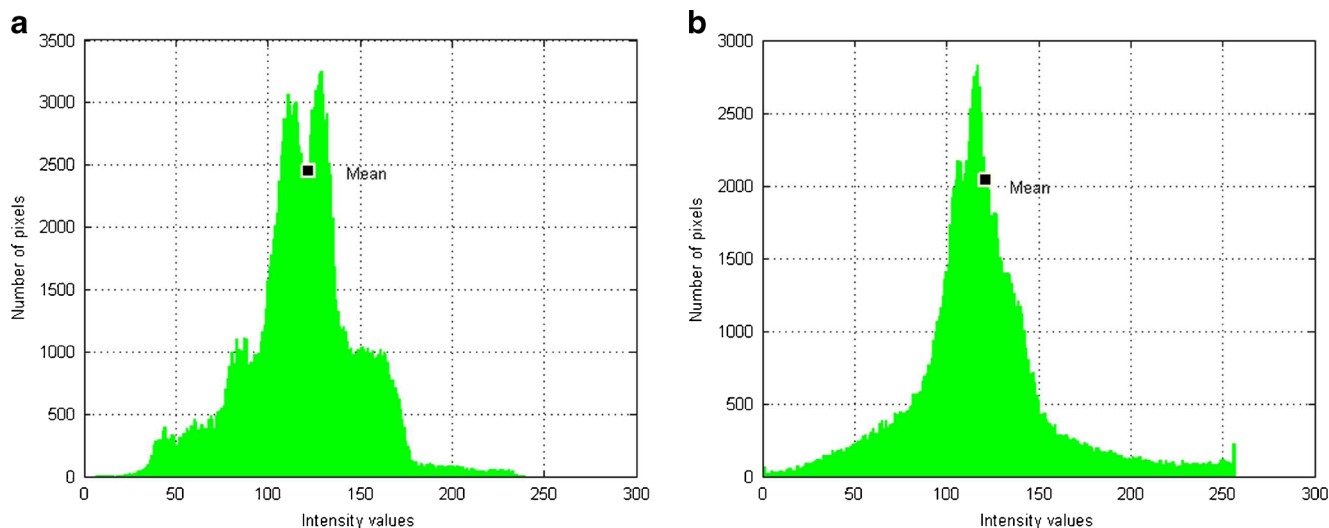


Fig. 6 (a) Positive kurtosis and (b) Negative kurtosis distribution

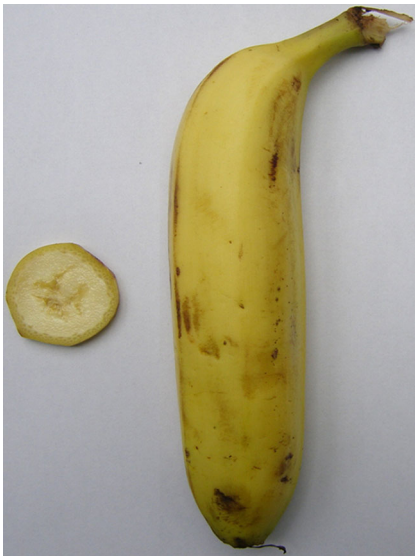
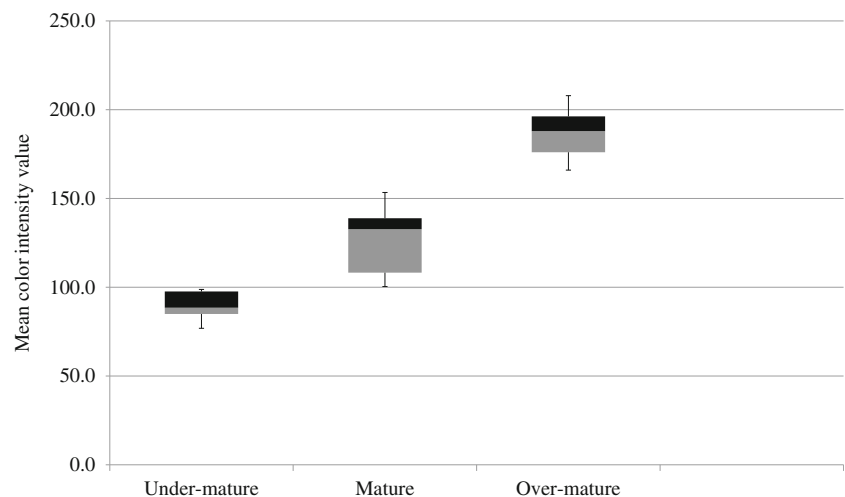


Fig. 7 Cross section of banana used as reference object for size calculation

region. The perimeter of fruit was measured using total number of pixels in the boundary region of the fruit. Major axis length and minor axis length of the banana fruit were also measured using regional descriptors available in an image processing toolbox of matlab. The measurement units of area, perimeter, major axis length and minor axis length of the banana image were in pixels. These pixels were converted into a centimeter measurement unit for easy recognition by farmers on the size of banana. Conversion was made by using a reference object with known size values for a standard pixel count. The cross sectional cut of the banana was used as the reference object (Fig. 7). The blue print of the cross sectional banana was taken in a graph sheet. Area and perimeter of the cross sectional banana were measured using the co-ordinate geometry from the graph sheet.

Fig. 8 Box-and-whisker plots representing mean color intensity value of under-mature, mature, and over-mature banana fresh fruits



Area of the cross sectional banana using the co-ordinate chain values can be measured as;

$$\text{Area of polygon} = 1/2[(x_0y_1 - x_1y_0) + (x_1y_2 - x_2y_1) + (x_2y_3 - x_3y_2) + (x_3y_0 - x_0y_3)] \quad (7)$$

where (x_0, y_0) , (x_1, y_1) , (x_2, y_2) , (x_3, y_3) are the co-ordinate values of the polygon.

Length and width of the reference banana object was measured using the Pythagoras theorem (Vince 2010). The distance between two points in the co-ordinate geometry is represented as;

$$\text{Distance} = \sqrt{\Delta x^2 + \Delta y^2} \quad (8)$$

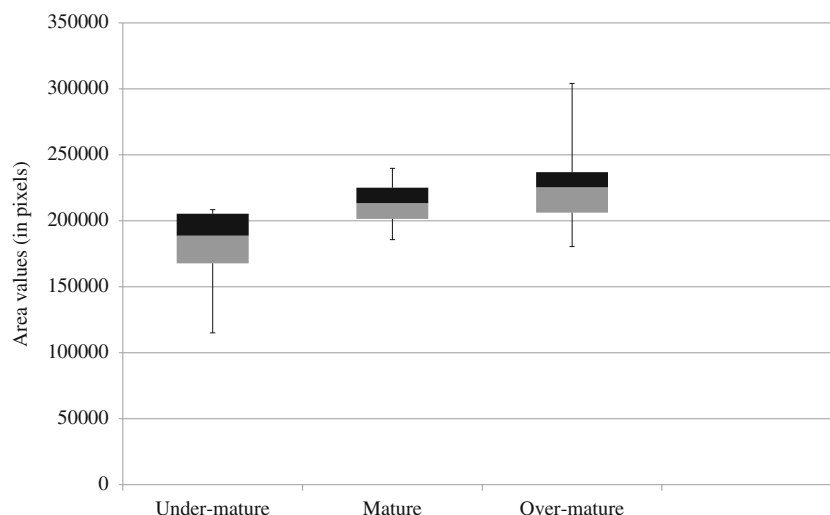
where $\Delta x = (x_2 - x_1)$ and $\Delta y = (y_2 - y_1)$. The intersection points of (x_1, y_1) , (x_2, y_2) were considered for the distance measurement. The perimeter of an object was calculated as sum of length of the object from each side.

The image of the reference object was taken and its values in pixel were calculated for the area, perimeter, major axis length and minor axis width. The measurement unit in centimeter and the pixel value of the reference object were compared and the value of one pixel in centimeter was measured and used to calculate the size of the banana in centimeter.

Data analysis

The color mean intensity value, area, perimeter, major axis length and minor axis length data were collected from 20 CI in each category (under-mature, mature and over-mature). Analysis of variance (ANOVA) with Duncan's multiple range test

Fig. 9 Box-and-whisker plots representing area value of under-mature, mature, and over-mature banana fresh fruits



(DMRT) was used to compare the significance of datasets of color mean intensity value, area, perimeter, major axis length and minor axis length between each banana group. Each maturity category was considered as one separate treatment and the number of images used for each maturity categories were considered as replicates comprising a total of three treatments replicated 20 times. Data set were randomized according to completely randomized block design. The data were analyzed using ANOVA and treatment means were compared by DMRT (Panse and Sukhatme 1989). The software used for analysis was IRRISTAT version 92 developed by the International Rice Research Institute Biometrics unit, Philippines.

Classifier algorithms

Two classifier algorithms were developed from the datasets of color mean intensity value and area. The datasets were analyzed using box and whisker plot technique (Figs. 8 and 9). Analysis indicated that none of the outlier samples were detected from the datasets and thus the calibration image

dataset was used to fix threshold values for developing an algorithm. The algorithm was written using the Image processing toolbox of matlab 7.10 (The Math Works, Inc., and Natick, MA, USA). The accuracy of the algorithms was evaluated using both calibration images and validation images.

Detection of maturity of banana

The maturity determination of banana was automated using the Graphical User Interface Development Environment (GUIDE) of matlab7.10. The developed algorithm in the Image Processing Toolbox of matlab 7.10 was linked to the GUIDE. The GUIDE is a user friendly and is easily accessible by the end user.

Results

The color intensity values of three maturity category of calibration images of banana fruit yielded distinctive histogram

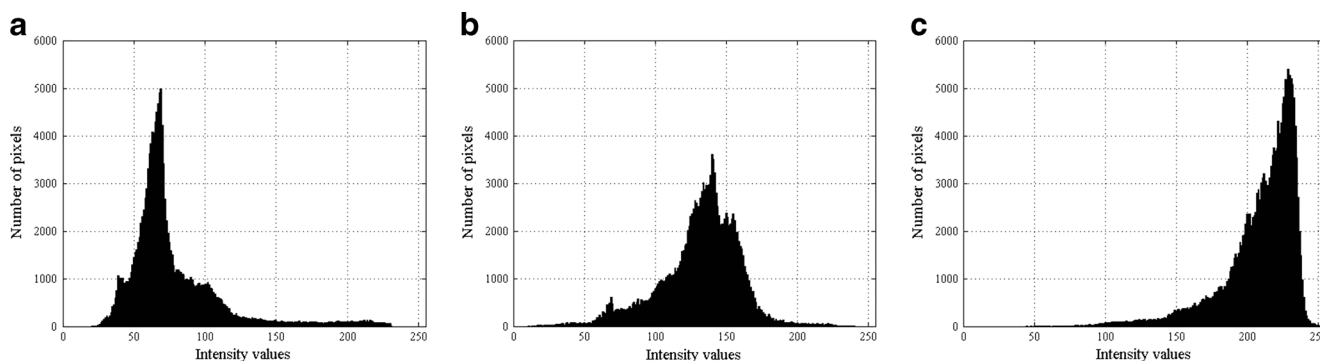


Fig. 10 Histogram of (a) under-mature, (b) mature, and (c) over-mature samples

Table 1 ANOVA results comparing the means of colour intensity value, area, perimeter, major axis length and minor axis length between treatments (Under-mature, mature and Overmature)

Feature	Mean colour intensity value (Pixels)	Area (Pixels)	Perimeter (Pixels)	Major axis length (Pixels)	Minor axis length (Pixels)
Under-mature	0.352492 c	191395.2 b	2443.4 a	993.8 a	341.3 a
Mature	0.493275 b	215708.5 a	2543.7 a	1041.3 a	354.5 a
Over mature	0.73096 a	223864.1 a	2600.2 a	1019.6 a	363.7 a
LSD (0.05)	0.0435	25731.5	—	—	—
SEM±	0.0163	9655.6	NS	NS	NS
CV%	9.83	9.50	—	—	—

Means in the same column with different letters show significant differences after one-factor ANOVA and Duncan multiple range test ($p < 0.05$); NS – Means of under-mature, mature and Overmature treatments in the column are not significantly different

distribution corresponding to each maturity category (Fig. 10). Statistical central moments from the histogram were calculated for each category. It was noted that the histogram of under matured banana clustered towards the lower end of the x-axis and the over matured banana clustered towards the higher end of the x-axis. The optimum matured banana had a histogram distributed and clustered in the centre of the x-axis. Mean color intensity value extracted from calibration images are given in Table. 1. It shows that the over matured banana had a mean value in higher intensity range (> 0.6) and for an under matured stage the mean lies in lower intensity range (< 0.4). The mean ranges within 0.4 to 0.6 for matured banana. As for the variance, over-mature images had the biggest spread compared to those data from mature and under-mature banana images (Fig. 11). The distribution of smoothness was similar to the variance (Fig. 12). Shape of the distribution was mostly negatively skewed in over matured banana and positively skewed for under matured and matured banana (Fig. 13). Kurtosis was positive for all maturity stages of banana (Fig. 14).

This leptokurtic distribution of a shape describes the intensity of color were clustered around the mean intensity value. The statistical central moments showed that mean color intensity value was considered as important feature to determine maturity of banana. In addition, size values such as area, perimeter, major axis length and minor axis length were also extracted from calibration images and their potentials were evaluated along with the mean color intensity value through ANOVA test.

There were significant differences among the three maturity stages of the banana in their mean color intensity value ($F=274.3$; $df=2, 59$; $P \leq 0.0001$) with over-mature banana having highest mean intensity value (0.73096) followed by mature banana (0.493275) (Table 1). The lowest mean color intensity 0.352492 was recorded for under-mature banana. There was no significant difference among the three maturity classes in the size value features such as perimeter, major axis length and minor axis length. However, under-mature banana had significantly lesser area when compared to the mature and

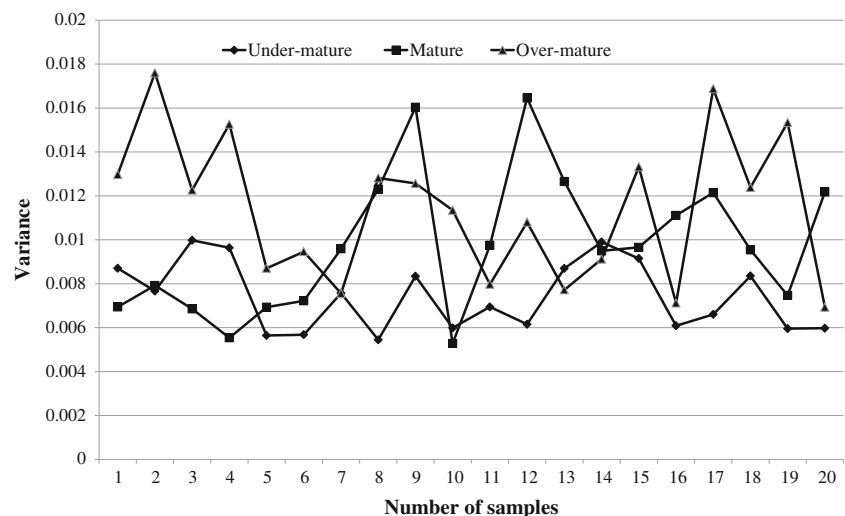
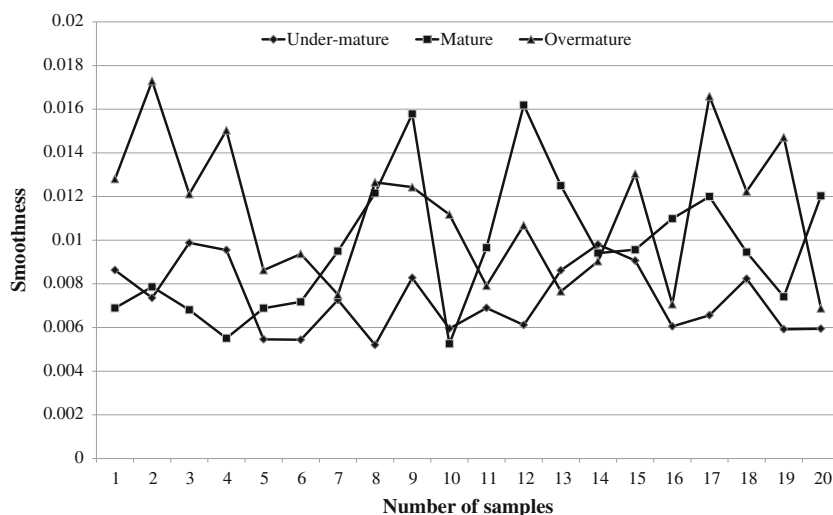
Fig. 11 Variance for under-mature, mature and over-mature samples

Fig. 12 Smoothness for under-mature, mature and over-mature samples



over-mature banana ($F=6.1$; $df=2, 59$; $P\leq 0.0004$). Hence, the two classifier algorithms based on color intensity value and area were developed and evaluated for their accuracy in this study.

The classification accuracies from two classifiers are given in Table 2. Mean color intensity algorithm performed better than area algorithm in predicting the banana fruit maturity. It detected under-mature banana fruit with 95–100 % accuracy, mature and over-mature banana fruit with 100 % accuracy. But, area algorithm performed better (85–100 %) only in identification of under-mature banana while the accuracy was less to detect mature (45–60 %) and over-mature (15–20 %) banana fruit. The color value from the three maturity stage of banana alone was found to yield overall good prediction accuracy which amounts to be higher than 95 %.

Maturity detection was made simpler, easier, faster and user friendly by using the GUIDE toolbox of matlab (Fig. 15). The mean color intensity algorithm and area algorithm were combined together in the GUIDE environment.

Since the mean color intensity algorithm established 99.1 % accuracy, the threshold value of mean color intensity algorithm was used to get the result of banana maturity category. The area, perimeter, major axis length and minor axis length values were displayed in GUIDE output. Maturity of the banana was determined efficiently in lesser time and the result showed physical, statistical measurements and the maturity level of banana.

Discussion

Earlier, the color features from banana fruit images were used to predict the post harvest ripening stages of banana and achieved 94–98 % accuracy, which could be beneficial to the banana fruit traders (Mendoza and Aguilera 2004). Quevedo et al. (2008) used the color information from digital images to detect browning of raw banana fruit and attained 35 times higher accuracy when compared with the traditional

Fig. 13 Skewness for under-mature, mature and over-mature samples

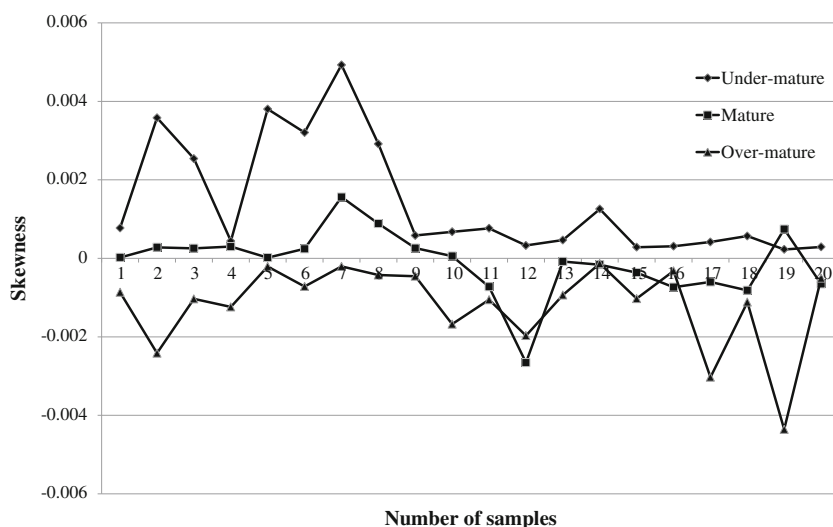
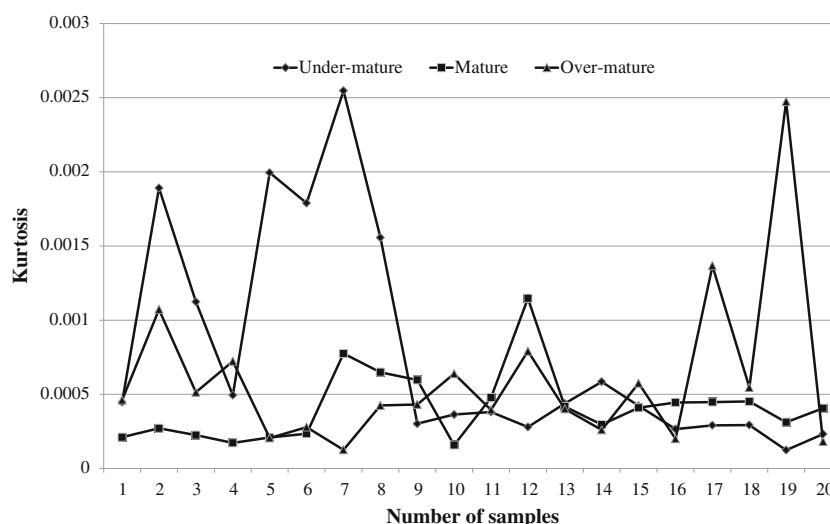


Fig. 14 Kurtosis for under-mature, mature and over-mature samples

method which was proposed to be beneficial in banana post harvest processing industries in quality control. Mustafa et al. (2008) suggested that the first step to determine the maturity of banana fruit is by recognizing the color parameter. This study confirmed earlier hypothesis and established that the mean color intensity value is a viable prediction feature to determine banana fruit maturity. However, 5 % misclassification was observed in the detection of under-mature fruit which might be due to the presence of the black color dried flower petal in distal end of the fruit (Fig. 1). This problem could be rectified through manual removal of this dried black petal from banana fruit before they are captured in the camera.

Both the color and size could play a vital role in maturity detection of banana fruit (Mustafa et al. 2008). The results of this study are in contrast to the earlier speculation. Although the size feature algorithm showed up to 85 % accuracy to detect under-mature banana, it detected mature and over-mature banana with low accuracy. The DMRT during ANOVA indicated that mean area value for mature and over-mature banana were almost similar. This explains the reason

for lower classification accuracies (15–60 %) in mature and over-mature banana detection.

Maturity assessment of fresh banana fruit is an important decision making factor that determines the marketability and production of quality banana fruit by the farmers. Fruit develop their full characteristic flavour, taste and color during storage if picked at optimum maturity stage. This study investigated a simple, non-destructive, image processing technique for determining fresh banana fruit maturity. The mean color intensity algorithm could predict the banana fruit maturity with an average overall classification accuracy of about 99.1 %. Thus, this system could potentially be applicable in predicting the fruit maturity before harvest, and to harvest the fruit in the appropriate stage to make the banana production economical.

This study aimed to predict the maturity of banana fruit using images of banana fingers acquired under controlled illumination condition. Under field conditions, banana fruit fingers existing as bunches are exposed to differential illumination conditions. Hence further research efforts are needed while devising field level computer vision system. Algorithm

Table 2 Accuracy rate of color intensity and area algorithms in banana fruit maturity detection

Category	Detection accuracy of algorithms (%)			
	Color mean intensity		Area	
	Calibration images	Validation images	Calibration images	Validation images
Under-mature	100	95	100	85
Mature	100	100	60	45
Over-mature	100	100	20	15
Total accuracy	100	98.3	60	48
Over all accuracy	99.1		54.0	

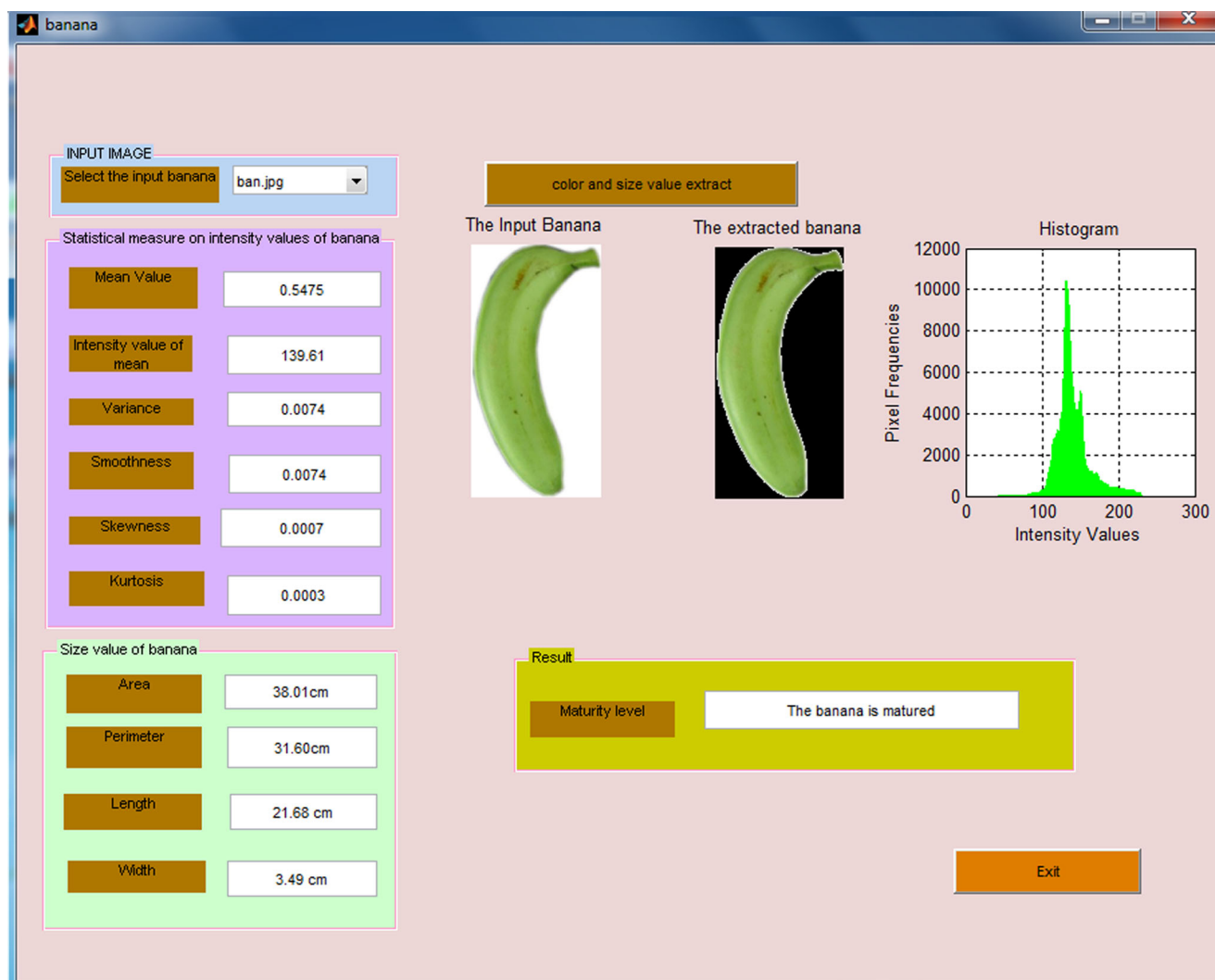


Fig. 15 Identifying maturity of banana using graphical user interface development environment in matlab

developed in this study work well for assessing maturity of banana fruit bunches in field environment only after threshold using larger image data sets acquired in field conditions.

Conclusions

This study explored color and size value features of fresh banana fruit images to classify under-mature, mature and over-mature category. It was found that the mean color intensity and area features were more significant among the different maturity stages than other features such as perimeter, major axis length and minor axis length. Mean color intensity and area algorithms were developed and tested for the accuracy on determination of fruit maturity. Testing of these two classifier algorithms indicated that mean color intensity algorithm was more accurate with overall accuracy of 99.1 %. The area algorithm was accurate up to 85 % for differentiating under-mature banana, but unsuccessful to distinguish between

mature and over-mature category. Since both the color and size value are reliable index to determine the right time of harvest; the mean color intensity algorithms in-conjunction with area algorithm developed in this study could be employed commercially while devising a complete field based automatic detection system for banana fruit maturity detection.

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