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Mangosteen Quality Grading for Export Markets Using Digital Image Processing Techniques

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***Abstract*— Accurate quality grading of mangosteen to meet the needs of consumers is very important for improving the value of the export business. Mangosteen fruit ripens quickly after harvesting, and shipping transportation time is a critical factor. Traditional grading methods by physical visual inspection result in delays and human-induced errors. This paper proposed an automatic grading system of mangosteen fruit that utilizes image processing techniques. The maturity stage, class, and size of mangosteen for the export market are analyzed. There are seven stages of maturity from stage one through to six and the under the mature stage, four classes (extra class, class B, class C, and non-standard class) and seven sizes (Jumbo through to Mini). Skin color, skin defect areas, completeness of calyx integrity are also considered. The preprocessing steps consisted of noise removal using a median filter and image enhancement using the grey level transformation. A combination of the mean intensity of red and green images was used to classify the maturation of the fruit. Areas damaged by yellow latex, cracks, and insect pests were extracted, and calyces were counted for class sorting. The length of the diameter was used for size classification. The thresholding, mathematical morphology, and extended minima transform techniques were also used. The average accuracy of the system was 99.54%, with a high accuracy rate for classifying the premium export grades. Results demonstrated that our proposed system was effective and could be used to improve productivity as an accurate and efficient grading method for mangosteen export.**

***Keywords*— Mangosteen; image processing; grading; export.**

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I. INTRODUCTION

Thailand is a bountiful source of diverse tropical fruits with a unique flavor. Mangosteen (Garcinia mangostana L.) has a high economic value as an export product. Mangosteen is believed to have originated in the Sunda and Maluku Islands of Indonesia and was later spread by humans to Malaysia, Thailand, the Philippines, and other Southeast Asian countries such as India and Sri Lanka. Mangosteen is now propagated throughout Central America in Guatemala, Honduras, and Puerto Rico. Known as the "Queen of Fruits", mangosteen has a high potential for export in Thailand. Currently, Thailand is the world's top exporter of mangosteen fruit to 14 countries, including China, Japan, Australia, New Zealand, Singapore, Indonesia, Brunei, the Philippines, Vietnam, Myanmar, India, Chile, Peru, and Hong Kong. Mangosteen is exported to other countries in both fresh and processed forms. Most of the fruit for export comes from 14 southern and eastern provinces. The top five plantation areas in Thailand are Chanthaburi, Nakhon Si Thammarat, Chumphon, Trat, and Rayong Provinces. In the east of the country, the production season runs from April to June, while in the south, it runs from July to September. Thailand exported mangosteen valued at USD 325 million in the first half of 2019, an increase of 220% over the same period of 2018 with a total market share of 97% in the major export markets such as China and ASEAN. Thailand exported mangosteen worth USD 229.4 million to China in the first half of 2019, an increase of 408% over the same period in 2018. This represented 71% market share for ASEAN [1-5].

The color of the mangosteen fruit is a major criterion for judging maturity and grading. As the fruit matures after harvest, the color changes from green to violet black. Growers and consumers use the color as a guide for quality. There are six color stages of maturity (stage 1 through to stage 6). The fruit is harvested from light greenish-yellow with scattered pink spots to dark purple [6]. Development of the fruit color rapidly decreases after harvest. Mangosteen is harvested for export at light greenish-yellow colour with scattered pink spots (stage 1) and ripens during transport to its final destination. If mangosteen is harvested too early, it will not develop to the mature stage. Late harvest increases the risk of spoilage during the delivery process. Mangosteen has many development channels to gain access to market opportunities. Product quality must be consistent and maintain standards. Most farmers sell mangosteen as mixed fruits that are not graded to meet market needs. Premium-grade mangosteen prices can be up to ten times higher than the lower grades. The task of grading is the responsibility of the export trader. Conventional grading is performed manually and requires at least three rounds of visual inspection by skilled workers. Lack of skilled staff is the main cause for delay in the grading step, which is very time-consuming and prone to human error.

Image processing techniques are widely used in the agriculture field for fruit maturity stage classification. Maturity determination using digital images has been tested on olive [7], banana [8], date [9], mango [10], plum [11], avocado [12], durian [13] and sweet cherry [14]. Mangosteen ripening classification stages were tested using a convolutional neural network by Aizat et al. [15] and achieved 91.9% accuracy. Mohtar et al. [16] proposed a deep learning method for mangosteen ripening stages classification. Sandra [17] proposed a mangosteen maturity index determination using a non-destructive method. RGB score with the thresholding method was used for three maturity classification stages by support vector machine (SVM) learning. The mean accuracy attained was 83.3%. A comparison between non-destructive and destructive methods was also proposed by Prabasari [18], while Rivadi et al. [19] tested mangosteen maturity stage estimation using a combination of SVM and color features. The SVM estimation required substantial training data sets, and only 24 mangosteen images were used. More data were needed as the accuracy was only 95.33%.

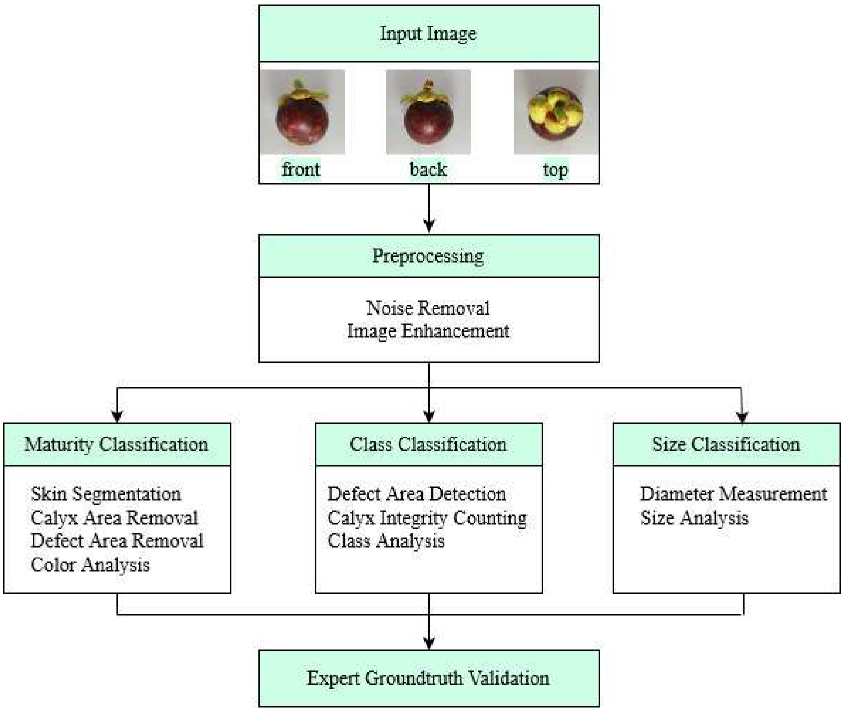


Fig. 1 The procedure of the proposed mangosteen grading system.

SVM methods have shown high accuracy rates but they require large computational capacity. Overfitting can occur when using a deep learning method based on training and testing data sets. We proposed a mangosteen grading system based on thresholding, mathematical morphology, and extended minima transform techniques. Using simple classification techniques, the system reduced computation time and specification requirements than the machine learning method required. Previous research only considered the classification of the maturity stage and did not cover grading for export quality. This research aimed to develop an automatic classification system for mangosteen export using an image processing technique. The stage of maturity, class, and size constraints were all analyzed and classified. Features of color, defective skin areas, completeness of calyx, and length of fruit diameter were also extracted. The proposed system procedure is demonstrated in Fig. 1.

II. MATERIALS AND METHOD

A. Data Sets

The mangosteen images used in this research were taken from several mangosteen plantations in Chantaburi Province, Thailand between January and April using a Canon EOS 550D digital camera. To simulate the distance of human visual inspection, the images were taken at a distance of about 35 cm. Image resolution was 375 x 375 pixels at 24 bits with JPEG image (.jpg) format file. To obtain the whole surface area, each mangosteen was captured on three sides: front view, back view, and top view. The front view of the mangosteen was captured first, and then the fruit was rotated 180 degrees to capture the back view. The front and back view were used for the maturity stage, size, and skin defect analysis, while the top view was used for calyx completeness analysis. A total of 720 images set comprised 120 images sets from each of the six stages of maturity. Eighty under mature images were also recorded. Each maturity stage image set contained all sizes and classes.

B. Preprocessing

The original RGB colour images were composed of R (red), G (green) and B (blue) planes. The blue plane image displayed the most distinctive separation between foreground and background images and was used as the initial image to segment the mangosteen image from the background image. To remove noise, median filtering with a 3x3 mask was applied. All pixel values were sorted in the specified window size and then replaced with the median pixel value. Grey level transformation [20] was used in the enhancement step. The input intensity image was transformed to output image using the transformation function. The enhanced image showed improved contrast with sharper details.

C. Stage of maturity classification

The mangosteen standard was proposed by the National Bureau of Agricultural Commodity and Food Standards [1] and Palapol et al. [6]. Six development stages include stage 1 through to stage 6: under mature (yellowish-white or yellowish-white and light green), stage 1 (light greenish-yellow with 5-50% scattered pink spots), stage 2 (light greenish-yellow with 51-100% scattered pink spots), stage 3 (spots not as distinct as in stage 2 or reddish-pink), stage 4 (red to reddish-purple), stage 5 (dark purple), and stage 6 (purple to black). The maturity stage is mainly classified according to fruit color. For exportation, the fruit should be harvested at stage 1. If the mangosteen is harvested when overripe, problems with time limitations occur during the exporting process. From stage 1, the fruit rapidly develops into purple to black stage 6 within 5-9 days, depending on temperature. However, if the fruit is harvested too early, it will not be fully mature. Our proposed system also experimented on the under the mature stage to overcome the problem of too early harvested fruit.

To classify the maturity stages, the skin color development in the outer pericarp of mangosteen was considered [21],[22]. Both front view and back view images were considered to cover all the skin surfaces. The preprocessed image was used as the initial image to extract skin surface defects. Sobel edge detection was utilized to locate the edge of the mangosteen accurately. The image was filled with white pixels to complete the whole fruit. Pixels with very small sizes were removed using the erosion method. The pedicel, calyx, and skin defects must first be removed to consider only the skin color.

1) Calyx area detection: To remove the calyx, the RGB color image was transformed to an HSI color image composed of hue (H), saturation (S), and intensity (I) modes. The hue mode represents the color property. In this step, the hue image was used as the initial image of calyx representation. The thresholding technique was then used to separate the whole fruit from the calyx. The resulting image was dilated to cover all the area and then eroded to precisely the actual size of the calyx. The dilation and erosion comprised mathematical morphological methods. Dilation expanded the object while erosion shrunk the object.

2) Skin defect areas detection: The yellow latex on the outer skin of the mangosteen is the most prominent constraint for mangosteen exports [23]. A yellowish colour on the skin characterizes this. Other skin defects include cracks and insect pest damage. To detect the yellow latex, threshold operation was applied at a selected grey level of the difference between green and blue planes, as shown in Eq. 1. Cracks and insect pest damaged areas appeared as dark red areas on the skin surface. An extended minima transform was applied on the hue colour image and a regional minima connecting the dark red areas was extracted based on the H-minima transform. The resulting image was then binarised by thresholding. The extended minima transform on the hue image with threshold value (α) is shown as Eq. 2. The skin detection result images are shown in Fig. 2.

$$Yellowlatex = T(Greenimage - Blueimage) \quad (1)$$

$$f_{crack} = EM(f_{hue}, \alpha \ ) \quad (2)$$

*3) Skin color analysis: After removing the calyx and skin defect areas, the intensity and mean intensity values of RGB and HSI colo*r plane images were investigated. All combinations of the image planes were tested. Results showed that a combination of average values of the red and green color images was the most impacting feature for maturity stage classification. The stage of maturity was classified by the mean intensity value of Red_{mean} and $Green_{mean}$ with a range of intensity values from 0 (black) to 255 (white) as shown in Table I. The mean intensity values of red pixels and green pixels were calculated using Eq. 3 and Eq. 4 as follows:

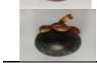
$$Red_{mean} = \frac{Sumofredcolourintensity}{Totalno.ofpixels} \quad (3)$$

where, Red_{mean} is the mean intensity value of red color

$$Green_{mean} = \frac{Sumofgreencolourintensity}{Totalno.ofpixels} \quad (4)$$

where, $Green_{mean}$ is mean intensity value of green colour

TABLE I
RANGE OF MEAN INTENSITY VALUES OF RED IMAGE AND GREEN IMAGE

	Stage	Mean intensity of red colour	Mean intensity of green colour
	under harvest	211-255	191-255
	1	201-210	176-190
	2	191-200	121-175
	3	121-190	71-120
	4	101-120	66-70
	5	71-100	61-65
	6	0-70	0-60

Referring to the intensity value from Table I, an example of classification condition is shown as follows: if (Red_{mean} = 201 & $Green_{mean}$ = 176) then the maturity stage is stage 1

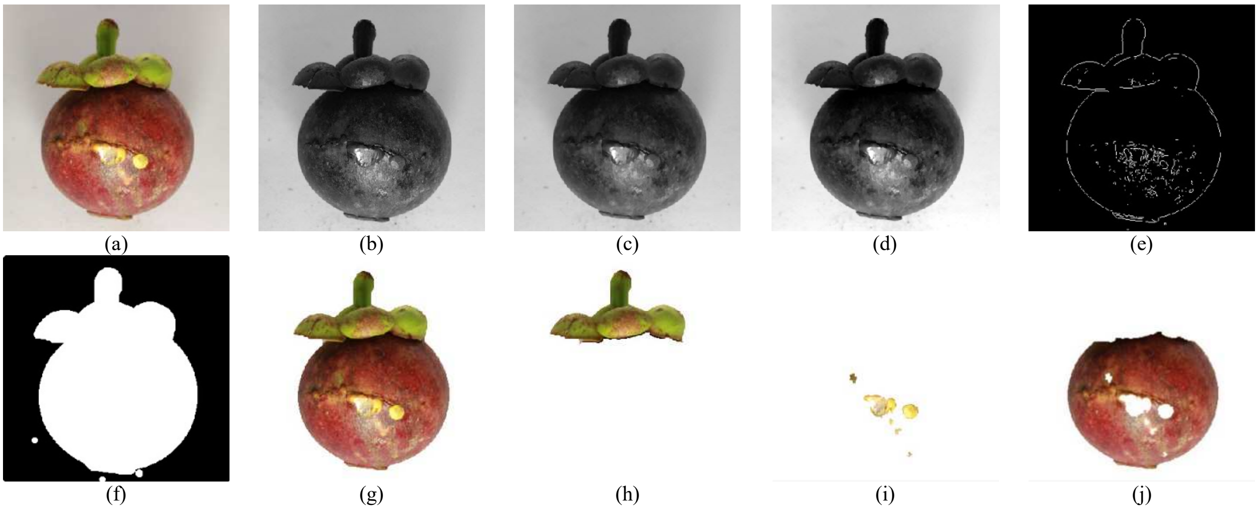


Fig. 2 Result image of skin segmentation (a) Original RGB image, (b) Blue image, (c) noise removal, (d) image enhancement, (e) edge detection, (f) filled image, (g) image without background, (h) calyx detected, (i) defect detected, and (j) surface image after calyx and skin defect areas removed.

D. Class classification

Mangosteen is classified into three standard classes, namely class A (extra class), class B (class I), and class C (class II), and non-standard class [1]. The percentage of skin defect area classifies each class. The overall skin defect size must not exceed a specific percentage of the surface area of the mangosteen fruit: class A (defect areas < 10%), class B (defect areas < 30%), class C (defect areas < 50%), non-standard class (defect areas ≥ 50%), while another constraint requires the complete integrity of the four calyces.

1) Percentage of defect area detected: The previously detected yellow latex, crack, and pest damaged areas were used. The percentage of the skin defect areas was calculated using Eq. 5. Images showing yellow latex and cracks areas are presented in Fig. 3.

$$percentage\ of\ defect = \frac{number of defect pixels}{number of all skin pixels} \quad (5)$$

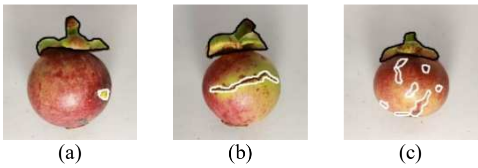


Fig. 3 Result image of defect areas detection (a) small yellow latex detected, (b) crack detected, and (c) yellow latex and crack detected.

2) Calyx integrity detection: The calyces are the greenish caps at the top of the mangosteen. Complete integrity required four intact calyces. To analyse the calyx integrity, the top view image of the hue plane was used. The calyx area was segmented and binarised using automatic thresholding as shown in Fig. 4(b). The distance from the center of the calyx area to the nearest pixel was computed as a circle radius (Fig. 4(c)). Then, a fitted circle was created (Fig. 4(d)). Fig. 4 (e) shows that each calyx was divided into distinct parts between the calyx region and the fitted circle. The calyx completeness condition was considered as follows:

if (the number of white connected objects) equals 4
    print "Complete calyx"
otherwise,
    print "Not complete calyx"

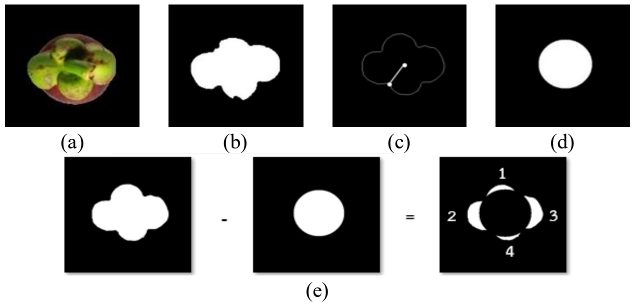


Fig. 4 Number of calyces detected from the top view image (a) original RGB image, (b) thresholding result, (c) edge detection and radius finding, (d) filled image and (e) result of calyx counting

E. Size Classification

The size of mangosteen is normally determined by weight per fruit. The standard size criteria of mangosteen used for export [24] are shown in Table II. The diameter of each mangosteen was measured by counting the number of pixels from the leftmost white pixel to the rightmost as pixels on the binary image, as shown in Fig. 5(b). The number of pixels was then transformed into a millimeter measuring unit for easy identification of mangosteen size by farmers. The conversion was performed using a reference object for a standard pixel count with defined size values. The results of images of each size are shown in Fig. 6.

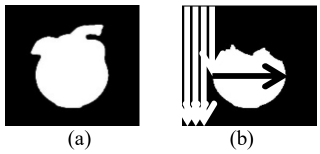


Fig. 5 Diameter measurements (a) binary image and (b) diameter measured on binary image after calyx removal

TABLE II
SIZE OF MANGOSTEEN FOR EXPORT

Size code	Size	Weight (gram)	Diameter (millimetre)
7	Jumbo	> 120	> 70
6	XL	116-120	66 - 70
5	L	101-115	60 – 65
4	M	86-100	55 – 59
3	S	76-85	50 – 54
2	XS	60-75	45 – 49
1	1	< 60	< 45

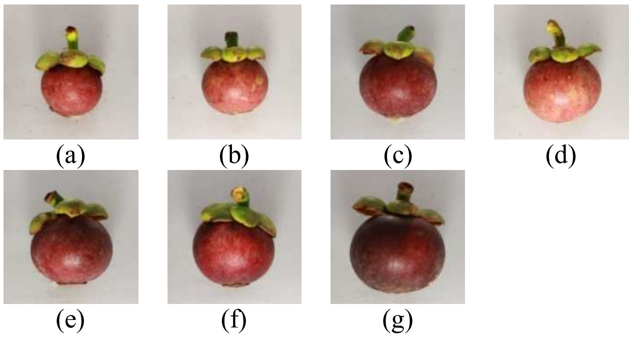


Fig. 6 Result of size classification (a) Mini, (b) XS, (c) S, (d) M, (e) L, (f) XL and (g) Jumbo

III. Results and Discussion

A total of 800 mangosteen images were tested, and the results were validated against mangosteen grading experts. The resulting images were compared with the ground-truth images used by the experts. The accuracy was computed by Eq. 6.

$$accuracyrate = \frac{correctlyclassifiedimage}{totalnumberofimage} x100 \qquad (6)$$

A. Maturity Stage Classification Results

There are seven stages of maturity for classification purposes, and 120 image sets were recorded for each stage, from stage 1 through to stage 6, with 80 image sets from under the mature stage. Results are shown in Table III. The results showed that stages 1, 3, 5, and 6 recorded 100% accuracy. The accuracies of the under the mature stage, stage 2, and stage 4 were 97.50%, 97.50%, and 99.17%, respectively. The average accuracy of all classification stages was 99.17%. The errors arose because the program detected faulty dark defect spots similar to the mangosteen skin. In practice, the most important stage of maturity for export is stage 1, which had a 100% accuracy rate. Caution must be observed in the under mature stage because if images are wrongly classified as stage 1, the fruit will not develop and ripen to maturity.

B. Size Classification Results

There are seven size classifications: Jumbo, XL, L, M, S, XS, and Mini. Two hundred images were tested for size Jumbo. One hundred images were tested for each size, with results shown in Table IV. Results showed 100% accuracy in size 7 (Jumbo), 6 (XL), 5 (L), 4 (M) and 1 (Mini), while size 3 (S) and 2 (XS) had 98% and 99% accuracy respectively. The average accuracy was 99.57%. The misclassifications in size 2 and size 3 resulted from very similar size differences.

C. Class classification results

The percentage of skin defect areas and calyx integrity were considered to classify the class. Standard classification recognizes three classes, namely class A (extra class), class B (class I) and class C (class II). For each class, 240 image sets were tested. The experiment also tested 100 images of the non-standard class and the results are shown in Table V. The results showed 100% accuracy in class A (extra class), class B (class I), and the non-standard class but in class C (class II) the accuracy was 99.58%. The overall average accuracy was 99.89%. One image in class C was wrongly classified as a non-standard class because the very small calyx was not detected.

The average accuracy of the system is shown in Table VI. Results were very good and close to 100% accuracy. Some errors occurred, as shown in Fig. 8. In Fig. 8 (a), the pericarp had both green and brown color, resulting in an incomplete detection of the calyx, while in Fig. 8 (b), missing cracks were found. To improve the maturity stage classification, faulty dark spots that could be classified as skin must first be eliminated.

Traditionally, mangosteen grading for maturity is performed manually by workers using visual processes. However, the visual approach is subjective and not reliable or consistent. During the post-harvest process, labor shortages also result in grading delay and excessive maturation of the mangosteen. The climate in Thailand is hot and dry, and mangosteen fruit cannot be stored for long periods. Mangosteen that cannot be sorted in time is sold in nearby countries, resulting in over-supply and low prices. Image processing technology implementation offers a better and faster standard classification method. To achieve trade quality standards, an automatic mangosteen grading system was presented. This research proposed an image processing technique based on median filtering, grey level transform, thresholding, mathematical morphology, and extended minima transform. The thresholding technique was based on parameters to adjust the value for the best results. Additional features such as the texture and shape of the fruit may also be considered to increase the accuracy in detecting defect areas. The determination of cracks and pest damage results was not complete, but the detectable defects were sufficient for class separation.

TABLE III
STAGE MATURITY DETECTION RESULT (NUMBER OF IMAGE SETS)

Standard \ Detected	Under mature	1	2	3	4	5	6
Under mature	78	2	-	-	-	-	-
1	-	**120**	-	-	-	-	-
2	-	-	117	3	-	-	-
3	-	-	-	**120**	-	-	-
4	-	-	-	-	119	1	-
5	-	-	-	-	-	**120**	-
6	-	-	-	-	-	-	**120**

TABLE IV
CLASS CLASSIFICATION RESULT

Standard \ Detected	A (Extra class)	B (Class I)	C (Class II)	Non-standard
A (Extra class)	**240**	-	-	-
B (Class I)	-	**240**	-	-
C (Class II)	-	-	239	1
Non-standard	-	-	-	**100**

TABLE V
SIZE CLASSIFICATION RESULT

Standard \ Detected	7 (Jumbo)	6 (XL)	5 (L)	4 (M)	3 (S)	2 (XS)	1 (Mini)
7 (Jumbo)	100	-	-	-	-	-	-
6 (XL)	-	100	-	-	-	-	-
5 (L)	-	-	100	-	-	-	-
4 (M)	-	-	-	100	-	-	-
3 (S)	-	-	-	-	98	2	-
2 (XS)	-	-	-	-	1	99	-
1 (Mini)	-	-	-	-	-	-	100

TABLE VI
THE AVERAGE ACCURACY OF THE PROPOSED SYSTEM

Constraint	Average accuracy (%)
State of maturity	99.16
Class	99.89
Size	99.57
Average	99.54

(a)

(b)

Fig. 7 Incomplete detection (a) calyx missing, (b) cracks missing

Currently, mangosteen sizing is accomplished using a highly-priced sizing machine. Our proposed system helps standardize the quality of export mangosteen fruit and reduces the investment cost. Quality fruit commands a higher sale price in the export market. China represents the largest export trading market and requires mangosteen in stage 1at 7A and 6A grades. Our proposed system performed with 100% accuracy and attained this requirement.

IV. CONCLUSION

This research proposed an automation mangosteen grading system for the export market based on the stage of maturity, class, and size of the fruit. Colour features were used to classify the maturity stage. Skin defect areas and the integrity of calyx features were also used to classify the mangosteen. The length of the diameter of the fruit was used to classify the size. Average system accuracy was recorded at 99.54%.

This computerized system does not replace human labor but greatly improves productivity, reducing the workload and improving grading uncertainties. A final visual inspection by the human eye is still required. Our proposed system utilized a simple but effective method with fast execution within half a second. Using image processing technology will greatly assist success in the mangosteen export industry.

In future studies, the calyx and skin defect detection results can improve accuracy. Embedding the proposed system in real sites should be tested to improve the quality of grading efficiency. Deployment of our system on a mobile application platform is challenging, but results can assist local farmers to self-grade their mangosteen quality. Machine learning methods will also be further investigated as the trade-offs between accuracy and complexity are still complex issues.

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