Automated Asian Fruit Grading System Using Stereo Vision Technique

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Abstract. In Malaysia, most of fruit planters are still using the conventional methods of inspection and grading their products by manual weightage measurement and visual inspection. Conventional methods rely on human eyes to perform the grading which leads to unproductive system and lack of data management. Therefore, in this study, an automated weight grading system is proposed to perform the grading system via size measurement using stereo vision system and image processing. The fruit selected to verify the system proposed performance were fruit samples provided by MARDI Bukit Tangga located in Kedah, Malaysia. In the vision system, triangulation method is used where the samples were graded more accurately using two cameras to form a stereo vision system. The image capture through the vision system processed using multiple image processing steps such as image segmentation, sobel edge sensor and multiple morphological operation. The relationship between weight and area of fruits done via regression methods with adjusted R-square of 0.9823. Using this goodness of fit, weight estimation can be executed with Root Mean Squared Error (RMSE) of 6.811. Overall, fruit grading system with the stereo vision of a low-cost web camera implementation has successfully performed with the accuracy of 85.65% and a Mean Absolute Percentage Error (MAPE) of 6.551%.

1. Introduction

Agriculture has a critical part in monetary development in Malaysia with underwriting 12% to the nationwide Gross Domestic Product (GDP) and giving work aimed at 16% of the populace up to the year of 2018 [1]. One of the areas that is basic to the commitment in agriculture is fruit production. The value of the fruits is imperative, intended for the buyers and led to the prerequisite from the providers to supply fruits with high ethics eminence. Therefore, within the past few years, grading system of fruit products has been set up to fulfill the industry review requirement of a natural product. There are few steps involved in fruit classification such as grading, sorting, packaging, transporting and storage. In agriculture, for high standard quality inspection, the grading system is considered as the most important steps and must be carefully executed.

In general, fruit grading involves sorting and classifying of the fruit conferring to the parameter such as sizes (diameter, length or shape). Thus, it is important in sorting classes for several diversities of fruit. There are numerous components that must be considered in fruit evaluation where weight, volume, shape, color, and exterior defects are exceptionally critical variables for fruit quality evaluation. While inner flavor variables such as sweetness, severity, causticity, saltiness, and
dampness and surface of fruit variables such as hardness, freshness and supplements, are truly influence natural product evaluation [2].

In Malaysia, most of the planters are still using the conventional methods which are weight measurement and visual inspection to inspect and grade the fruits. Based on Federal Agriculture Marketing Authority (FAMA), there are five main criteria of agriculture grading which consist of freshness, maturity, the damage, defects and uniformity of sizes [3]. This method is proven ineffective due to human error where irregularity in judgement diverse for each person and time consume [4].

In agriculture, there are two major technology area that is fast growing among researchers which are computer vision and image processing. Both areas, integrated together, formed a better performance of a system which increase its effectiveness and reliability. Hence, benefits in multiple type of agriculture activities such as agriculture produce evaluation by an imperative examining apparatus for pre-harvest to post-harvest of crops [5]. In land identification, image processing is used for identification of land that will be suitable for agriculture. In plant nitrogen identification, image processing used for estimation of plant nitrogen identification and chlorophyll identification [6]. In pesticide control, image processing is a powerful tool for identifying the plague - infected areas because it favors the development of the pestilence [7]. This has proven that image processing is widely used in agriculture.

Computer vision, like image processing plays a major role in determining or classify objects based on its input or criteria given [8]. One of the applications of computer vision with the embedded image processing, is to detect any defective of a subject such as crops. Wang Chuanyu, Guo Xinyu, and Zhao Chunjiang [9] used computer vision to measure the early stage of corn plant spacing and population. In agriculture science, plant steam can be measured based on computer vision and embedded system. For medical purposes, computer vision has many advantages such as in diagnosis and detect uncertainty such as cancer or tumor. Researchers such as Jerome Thevenot, Miguel Bordallo Lopez, and Abdenour Hadid prove that computer vision can be applied for the medical purposed as it can detect symptoms of a patient from their faces. In addition, a study by Emilio Jorquera-Fontena et. Al [10], on berry indicate that the weight-diameter relationship was sufficiently stable regardless of the genotype and growth. Their study shows that weight can be measured based on the diameter of the fruit. The author estimated the weight of fruit from equations using simple fruit diameter measurements. It can be a cheap and fast alternative for a precise measurement of fruit weight.

Therefore, in this study, a weight grading system based on size measurement is proposed to close the gap occur in their manual grading system. The system will estimate the weight in order to grade the fruits via its sizes. The fruit sample used in this project is mango fruit which is one of the popular fruit in Malaysia. The stereo vision is used to capture the image of the fruit and further processed via several image processing steps before estimating the weight using a mathematical modelling acquire from the relationship between weight and area of fruit. Mathematical modelling is a model type for explaining the system and studying the effect of a different component and for predicting behavior.

2. Materials and Methods
The proposed system comprises of a 2 mm acrylic sheet box with a dimension of 20 x 30 x 40 mm, calibration objects, two web cameras, test subjects (mango fruit) and a computer. A generic laptop is used for data collection, processing and monitoring purposes: Intel Core™ i5 7th Gen Processor @ 2.6GHz, 4.0 GB RAM, running MATLAB version 2015a (MathWorks, Inc.) and 64-bit Windows™ 10 operating system. The main components of this experimental setup are shown in Figure 1 and described briefly as follows.

2.1. Web Cameras.
In this research, the stereo vision method was used to capture and process the image. This method implemented by using two generic low-cost web cameras by Logitech. These cameras are fixed at the top of the acrylic box with distance between left and right cameras at 8 cm and test subject’s positions
at the bottom with height of 38 cm from the cameras external lens cover which is shown in Figure 1c. The stereo vision system with a low-cost web camera has a few known limitations where it has low in pixel and less clear image. Therefore, light play a major role in giving a much better-quality image. In this experiment, ambient light from the room was used to support the stereo vision constructed. The light brightness was enough to capture a good quality image to be processed further. Other than that, calibration processed was also done which is crucial in obtaining the important parameter such as focal length and distortions which will be used to rectified image between left and right image to be in the same baseline. It is also important in calculating calibration factor where this factor was used to obtain the real physical metrics of the fruits under test.

2.2. Fruit Sample and Data Collection

In this research, 82 mango fruit data consist of Mangifera Indica (Chok Anan mango) was selected to be used in regression analysis. The 'Chok Anan' mango, sometimes spelled Chocanon, is a sweet mango originated from Thailand, India, Bangladesh and Pakistan. It has an oval shape and tapered tips. It has light yellow and has a sweet taste when the fruit is ripe. The fruit was obtained from
Malaysia Agriculture Research and Development Institute (MARDI) Bukit Tangga/Sintok, Kedah. MARDI Sintok is one of the Research and Development (R&D) station that develop new way of breading and produce fruits that has high quality. There were two steps involved in measuring and collecting the fruit data which at first the actual weight of the samples was measured and recorded and then followed by measuring and recording the length and diameter of the samples. Figure 2(a) shows the mango fruit weighted using a digital weight scale, which is more accurate compare to mechanical weight scale. Figure 2(b) and Figure 2(c) shows the length and diameter of mango fruits measured using the digital caliper which also has a better accuracy in measurement.

2.3. Regression Analysis

In this section, regression analysis is presented. Figure 3 shows the allometric relationship between mango area and mango mass using MATLAB Curve Fitting Toolbox (CFT). CFT gives an app and capacities for fitting curves and surfaces to information. The allometric relationship are based on polynomial degree of two as it provides almost perfect curves with lower RMSE. Table 1 shows the fitness model between area, diameter and length of the mango samples. The fitness of area has an adjusted R-square of 0.9823 with RMSE of 6.811. The fitness of the diameter has the lowest adjusted R-square value with 0.918 but has the highest RMSE value of 12.85. As for fitness of length, the adjusted R-square is 0.9581 and RMSE with 10.3872. Hence, the best goodness of fit is area with the R-square of area is the highest and the dependent variable can be predicted with less error from the independent variable. The final regression analysis computes the mathematical modelling based on polynomial second order with the best goodness of fit as shown in equation (1). The linear model shown in Figure 3 compute the coefficients value of the polynomial of 1.705e-6, 0.01713 and 16.61.

\[
f(x) = (1.705e^{-6})x^2 + 0.01713x + 16.61
\]  

A common standard to measure the mean difference between expected data and observed data is by using RMSE. The RMSE serves to aggregate the magnitudes of the errors in predictions for various times into a single measure of predictive power. The best RMSE presented by area which also shown in Table 1 with 6.811 of value. The smallest the value of RMSE, the closer to the estimation it is [11].

Figure 2. (a) Weight measurement using Digital Weight Scale (b) Diameter measurement using Digital Caliper (c) Length measurement using Digital Caliper.
Figure 3. Allometric relationship between mango area and mango weight; x3 indicates area while y indicates mass.

Table 1. Fitness model between area, diameter and length of the mango.

| Fit Name (x)   | SSE(mm) | R-square | Adj R-square | RMSE  |
|----------------|---------|----------|--------------|-------|
| Diameter (x1)  | 9911    | 0.918    | 0.9153       | 12.85 |
| Length (x2)    | 6257    | 0.9581   | 0.9567       | 10.3872 |
| Area (x3)      | 2690    | 0.9823   | 0.9817       | 6.811 |

2.4. Vision System
The vision system proposed to use stereo vision with a triangulation method. The system comprises of four distinct stages which are calibration, fruit sample rectification, fruit sample segmentation, area measurement, weight estimation and fruit grading. Figure 4 shows the flowchart of the system proposed and are described as follows.

2.4.1. Calibration.
Image calibration offers a pixel-to-real-distance conversion factor (i.e. calibration factor, pixels / cm) allowing image scaling to units of metrics. This information can be then used throughout the analysis to convert pixel measurements performed on the image to their corresponding values in the real world. In this project the calibration method was adopted from Bouquet who developed the MATLAB Calibration Toolbox and acquired the process with the reference from Zhang’s method [12].

2.4.2. Image Rectification.
In image rectification, the data from the stereo calibration is loaded, which contains the extrinsic, and intrinsic parameters. The camera of each image will be turned to adjust its level line. The new intrinsic parameter will be calculated by using the equation (2) and is integrated in the Calibration Toolbox. At this point, the rectification is applied to the image. The next step was to adjust the camera orientation in parallel with the epipolar horizontal line. After that, for both left and right camera new intrinsic parameter will be commutated. Lastly, all image is rectified so that the next process can compute correctly.

$$I_{new}(x,y) = \alpha_1 I_{old}(x_1,y_1) + \alpha_2 I_{old}(x_2,y_2) + \alpha_3 I_{old}(x_3,y_3) + \alpha_4 I_{old}(x_4,y_4)$$

Where:

$I_{new}$ is the rectified image
\( I_{\alpha} \) is the original image \( \alpha \\
i \) is the coefficient of blending

2.4.3. Image Segmentation.

The image segmentation is applied with multiple dividing part which are Sobel edge detector, dilation, fill hole, border removal and erosion. The process begins with object detection on the rectified image through edge detection. Sobel Edge Detector is used in this process. The edge image detected can be obtained using a threshold value from this technique. The dilation of the object in a horizontal line follows the mathematical morphology method. For the next step, the internal gaps within the object hole are filled and the objects connected to the border are then removed. Lastly the image is smoothening by eroding the image. Image segmentation results for left and right camera is shown in Figure 5(a) and Figure 5(b). These figures represent the results of image segmentation which executed after image rectification in calibration process. In both figures, the Sobel edge detection and dilation process results are shown from the left image to the right image of the first row with the threshold of 0.5 applied to it. At the second row, the image shows the results of binary image after filled up the holes of the images and followed by removing unnecessary connection border. The last image shows the final object selected smoothen with erosion. All the image processed is executed on the object image one at a time where every samples image is repeated from the segmentation step until the removing of unnecessary connection border.

![Image Segmentation Flowchart](image.png)

**Figure 4.** System flowchart of Fruit Grading System.

2.4.4. Size Measurement.

At this stage another set of image processing method is used to calculate the size of the local fruit. Region extraction is the most important process at this stage. The process begins with loading the previous image done by segmentation step and followed by tracing the boundaries. This method of blob extraction is important because the measurement depends on the pixel connection of the region concerned. The next step is to label the region in which the tools measure multiple objects at once. The
blob properties then measure the area and perimeter of the previously labelled imaging regions. Finally, the measurement is converted to a SI unit and placed in a table to facilitate the viewing by using the calibration factor acquire during calibration. Figure 6, Figure 7 and Figure 8 present the image processing results towards the size measurement calculation. Figure 6 consists of the image smaller than 70 pixels that has been removed. The left image in Figure 7 shows threshold image where the region boundaries are traced. The right image is the resulting of the blob detection. At the end, the fruit image is labelled with numbers as shown in Figure 8 and the parameters measured will be showed according to the number labelled. However, in this project, the sample measure one at a time, the labelled number does not have any significant impact towards the parameters displayed. It will be beneficial when a weight estimation done with a multiple fruit sample at a time.

2.4.5. Weight Estimation and Grading.
At this last stage the weight estimation was done by using equation (3) which is based from the equation (1) obtained during regression analysis. The equation is used directly without having to change the SI unit as it has been converted during size measurement process with consideration of calibration factor. The weight is graded in gram while area in millimeter.

\[
Weight = (1.705e^{-6}) \text{ area}^2 + 0.01713 \text{ area} + 16.61
\]  

(a)
3. Results and Discussion
The estimation weight of the mango fruit samples by its size category was estimated using the grading system. The estimated grade mismatched between actual grade and estimated grade is shown in Table 2. There are few samples from each size category that was estimated out of its category. Grade XL and S have the wrong estimation compared to the grade L and M which occurs mainly due to irregular shaped of mango fruits that resulted in inaccurate area and weight estimation. Additionally, some of the estimated weights fall in between the grade categories and as such causing the misclassification. Table 3 show the accuracy, MAPE and standard percentage error of area and estimated weight grading.
Table 2. Quantity of fruit samples estimated using weight grading system and classified to its size category.

| Size | Actual Grade | Estimated Grade | Sample Mismatched |
|------|--------------|-----------------|-------------------|
| XL   | 0            | 1               | 1                 |
| L    | 20           | 17              | 0                 |
| M    | 33           | 32              | 0                 |
| S    | 2            | 5               | 3                 |

Table 3. Summary table of the experiment.

|                              | Calculated Area (%) | Estimated Grading (%) |
|------------------------------|---------------------|-----------------------|
| Accuracy                     | 88.606              | 85.65                 |
| Mean Absolute Percentage Error| 11.394              | 6.551                 |
| Standard Error               | 3.226               | 5.149                 |

In Table 3, the MAPE of the sample fruit area is 11.394% while for the mango fruit weight the MAPE is about 6.551%. Based on this table, the MAPE of the fruit area has higher percentage due to the image segmentation process. In Sobel edge detection, the object regional is using 0.5 threshold so that it can be traced successfully. This threshold value effect the behavior of the segmentation process due to a limitation whereby if the image is high in contras, the detection process has an error as high contras which lead to excessive pixelated. Contradictory, low in image contras can lead to an error for the Sobel edge detector to detect the border line of the image. This situation can cause a problem when gathering the information needed before the calculation process executed.

Another factor that contribute the high MAPE value of the area is the stereo vision cameras. The cameras used are low-cost web cameras which is low in resolution. Due to this limitation, it is significantly affected the process when evaluating the mango image. With low resolution on the cameras, the detail of the image decreases thus make the edge detection process unable to be segmented accurately. Although using low-cost cameras have many disadvantages, the result obtained shows a high grading efficiency with producing more than 85% of accuracy. Although the efficiency is at an average level, the system is still able to achieve a lower MAPE and standard error at 6.551% and 5.149% respectively.

4. Conclusion
Based on the results, the fruit grading system with the use of a low-cost web camera was satisfactorily estimated via weight based on area with an accuracy of 85.65% and MAPE of 6.551%. Despite that the results show to be reliable for estimating the weight of mango fruit, it must be validated when implemented to other genetic or type of fruit. In order to reduce the cost of using a higher resolution camera, a web cam was used, and it is significantly affected the process when processing the images taken. With low resolution, the detail of the image decreases, thus impacted the edge detection process. During the process, the threshold factor is the parameter that have significant effect towards the accuracy of pixel measurement in determining the size of the objects. At a very small factor, it results in a larger edge being detected while at higher threshold factor, a much smaller edge detected, and objects may be detected intermittently due to a smaller number of pixels.

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