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Assessment of palm oil fresh fruit bunches using photogrammetric grading system

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Abstract: The agricultural industry scenario in many industrialized countries has adopted an image processing system as a solution to automate the grading process in order to provide accurate, reliable, consistent and quantitative information in addition to the large volumes, which human graders are not able to perform. In Malaysia, the grading of palm oil Fresh Fruit Bunches (FFB) is still performed manually through visual inspection using the surface color as the main quality attribute. It is the intention here to introduce an automated grading system for palm oil FFB using a computer assisted photogrammetric methodology which correlate the surface color of fruit bunches, not the fruitlets, to their ripeness and eventually sorts the fruit to two predefined fruit categories. The methodology consists of five main phases, i.e. image acquisition, image pre-processing, image segmentation, calculation of color Digital Numbers (DN) (data manipulation) and finally the classification of ripeness. This computerized photogrammetric image processing technique using MATLAB® package which is integrated to a sorting system differs in various aspects from other digital imaging technique or machine vision system adopted for classifying fruit ripeness. A comprehensive discussion will be presented based on the results achieved through actual fruit testing on the prototype grading system. The main concern was to ensure the reliability of the computerized photogrammetric technique achievable and the system's mechanism working as intended. The fruit classification ability of the system yields above 90% accuracy and taking not more than 25 seconds to classify and sort each fruit.

Keywords: Palm oil FFB, surface color, image processing, automated grading system, ripeness index value

Introduction

A number of fruit and vegetable grading and sorting systems have appeared in several countries to fulfill the needs of the agricultural industry. Present sorting system may include the development of an electronic weighing system and a vision-based sorting and grading unit which also measures size, with a friendly user interface which is enable to define the classification parameters, reconfigure the outputs and records production data and statistics. Machine vision system has been widely accepted in recent years as a form of inspection system to identify fruit size, color and weight that correlate to its quality. The technology is able to analyze and interpret images of the fruits in a manner resembling to a human vision (Chen, 2000; Tadhg and Sun, 2002; Abdullah *et al*., 2004).

In the palm oil mills, manual grading process through human vision is still being practiced in local plantations. Color of palm oil fruits remains one of the important factors which determine the grade and quality of the palm oil (Malaysian Palm Oil Board, 2003). Thus, vision system will be the most appropriate method of palm oil FFB grading which will be less tedious, time-saving, not subject to errors and inconsistencies. The color of each fruit on the bunch varies slightly with location as fruits on any given bunch do not ripe simultaneously. In spite of this, it was observed that more than 85% of fruits on any bunch exhibit a similar degree of maturity, the remaining 15% which are hiddenly located in the interior regions of the bunch constitute the undeveloped and parthennocarpic fruits (Wan Ishak *et al*., 2000). Hence, it can safely be inferred that once a fruit within a bunch is ripe, all other fruits on the bunch are physiologically ripe as well.

It is the main aim of this research work to develop a computer assisted photogrammetric grading that comes together with an automatic FFB fruit sorting system to replace the manually graded and sorting practice at palm oil mills. This has led to the use of a machine vision system to capture the fruit images, process and analyze them based on the color data obtained before sorting the fruits according to its predefined ripeness category.

The surface color of palm oil FFB can be used as a yardstick to determine the inspection criteria for food quality that indicate its maturity or defects. A number of commercial color meters are available

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for the measurement of fruit ripeness. However, the disadvantage of using such method on palm oil FFB is that the destructive testing can only be done on the fruitlets of the fruit bunches and it requires the fruits to be sliced and the surface of the mesocarp exposed (Idris *et al*., 2003). However, studies have found that the oil content of the flesh of the mesocarp has direct relationship with the fruit surface color and this can be used as an indicator of palm oil quality (Balasundram *et al*., 2006). Hence, in order to increase the efficiency and quality of grading FFB in palm oil mills, a fruit grading system based on computer-based technologies such as machine vision (Yud-Rec *et al*., 2002; Abdullah *et al*., 2005; Meftah Salem *et al*., 2008; Narendra and Hareesham, 2010) are necessary to replace the traditional grading performed by trained human inspectors. Up to date, most of the work carried out in capturing the fruit images was done using a stationary fruit sample and tested out manually. The image processing technique is commonly programmed to run on specific image vision software. Whereas this novel image processing methodology is assisted by customized hardware and software systems that would carry out the on-line grading and sorting process which would hopefully increase the FFB grading consistency and reduce sorting time.

The application of machine vision system is widely studied by researchers from local institutions and had been applied in grading fruits such as starfruit (Abdullah *et al*., 2005), papaya (Slamet *et al*., 2007) and Jatropha Curcas (Zulham *et al*., 2000). Different approaches were used to determine the fruit ripeness index or maturity, size and quality with color remains as one of the important factors to determine the grade and quality of the fruits. The maturity or ripeness index was based on color intensity. It was recorded that, a computer program was developed and the mean color intensity was used to differentiate between the different color and ripeness of the fruits such as palm oil FFB. Most of the machine vision grading system employs a standard methodology such as image acquisition, image processing and computing the result. Image acquisition is one of the most important processes for the performance of a machine vision system, because with a high-quality image obtained, the following processing and analysis of the image would be easily feasible.

The novel methodology that has been developed for this research is known as the photogrammetric grading of oil palm fresh fruit bunches and primarily consists of five main phases, i.e. image acquisition, image pre-processing, image segmentation, calculation of color Digital Numbers (DN) (data manipulation) and finally the classification of the FFB ripeness. The analysis is carried using MATLAB® image processing toolboxes running on Windows® platform. The image pre-processing phase comprises of three steps, i.e. image binarization, morphological processing and the extraction of FFB properties. Similarly, the image segmentation phase comprises of another three different steps, i.e. image cropping, conversion from RGB to $L^*a^*b^*$ color space and the segmentation of FFB image using K-means clustering. The schematic flow of the methodology is represented in Figure 1.

For comparison purposes, the average digital numbers of the unsegmented and segmented FFB images are computed. The calculation process will consider both the masked and the FFB image as the input to calculate the average RGB color intensities or digital number (Meftah Salem *et al*., 2008). Each layer of RGB was totaled-up, and divided by the total numbers of pixels in the masked image to obtain the average DN value. The color values were then computed to get the values for R/G and R/B. To emphasize the difference between ripe and unripe classification, the maximum values of these ratio were then used to calculate $R/G^*R/B$. The output value obtained from this stage of data manipulation is known as the ripeness index. The ripeness index will be the main parameter used to classify the ripeness of the fruits.

Image cropping is one of the most important steps in the image segmentation phase. The aim of image cropping is to reduce the image size for further analysis in order to increase the computational speed. In order to obtain better cropped image, it is very much dependent on the background color that is used during the image acquisition process. In order to enhance the image quality, it is recommended that the FFB is clean from dirt to minimize or eliminate the noises or disturbances generated during the image pre-processing stage. However, during harvesting, it is difficult to control the cleanliness of the FFB and thus the image processing algorithm has to be designed to overcome this problem.

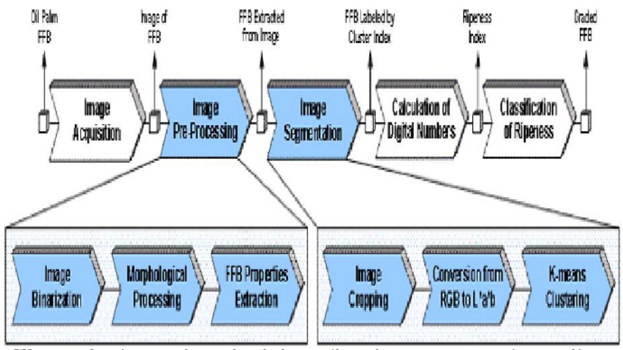

Figure 1. A novel methodology for photogrammetric grading of palm oil FFB

System components

The computer vision field has made significant progress in the last few years and hardware capabilities have improved very fast, providing powerful electronics and low cost architectures for the use of many purposes. Hence, this specially developed system was built to function as intended with the use of low cost accessories and standard hardware as possible without sacrificing the quality, speed and accuracy of the measurement. The use of frame grabbers, high resolution CCD color cameras and sophisticated software have been omitted and substituted with much lower cost architectures (Tadhg and Da-Wen, 2004).

Hardware system

The complete photogrammetric grading system consists of a flexible modular system which comprises of (i) a feeder unit that is connected to the conveyor which feeds the FFB to the inspection chamber in a systematic manner, (ii) an inspection chamber module which comprises of an illumination system, two webcams for acquiring for the FFB images and a workstation for processing and storing of images, (iii) image processing module, and (iv) a separator that physically separates the FFB according to its ripeness. The sequences of the grading process are controlled by using a programmable logic controller (PLC). The data acquisition (DAQ) card is used to integrate the image processing module to the automated grading and sorting system. A schematic diagram of the integrated photogrammetric grading system is shown in Figure 2.

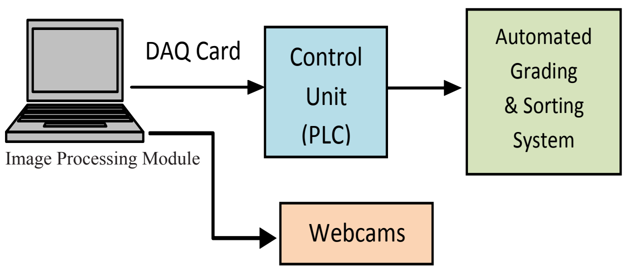

Figure 2. Integrated photogrammetric grading system

The purpose of the feeder is to load the FFB to the conveyor. Implementing a gravity concept using rollers, the feeder unit is capable of storing about 5 to 6 FFB at a time before loading each of the FFB to the conveyor. The conveyor in this automated grading system is to deliver the FFB through the inspection chamber and then sort it into its respective collecting bins after the fruits are categorized. The initial idea to use a roller conveyor was replaced by a slat conveyor which is more capable of handling the heavy FFB and generates less noise. The dimensions of the conveyor are approximately 2098 mm in length and 590 mm in width. The conveyor comprises of a few components such as sprockets, chain and a motor. The motor has a variable speed which allows the user to adjust and synchronize the speed to the webcam's frame rate and processing time. However, by implementing a slat conveyor type, it has a slight effect on the output of the fruit images during the cropping process. The image cropping process relies on the background color and requires a uniform surface. Unlike in a flat belt conveyor, the slat conveyor comprises of individual plates that are connected together and produces narrow gaps in between due to its mechanical design. The output of the cropping images can be seen in later section of this paper.

The illumination system of the inspection chamber aims to maintain a uniform lighting condition during the image acquisition phase. The inspection chamber walls were painted white and four white 8-watts fluorescent tubes were installed on the chamber's roof. To ensure cost competitiveness of the system, the image capturing was done using two high end Microsoft Lifecam NX-6000 webcams which are capable of producing 2.0 megapixel video with a resolution of 1600x1190 pixels. Designed for mobility and durability, the lens is fully collapsible and retracts inside the aluminium body of the webcam when not in used. The entrance and exit opening of the inspection chamber are approximately 580 mm in width. The vertical distance between the webcam and the fruit is about 350 mm. Figure 3 shows the inspection chamber with the lighting and vision system in placed and illustrating a stationary FFB in position waiting for its image to be acquired and processed.

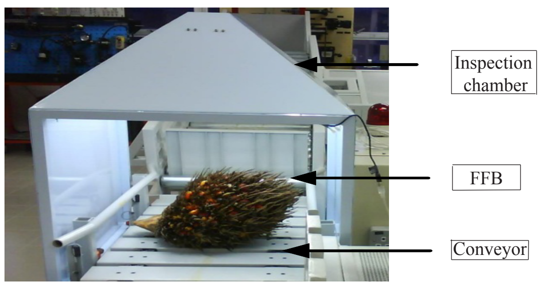

Figure 3. Inspection chamber with lighting and vision system

Software system

The images of the FFB are captured using webcams and the analysis is carried out using MATLAB®. The image processing algorithms are integrated to a Graphical User Interface (GUI) of the photogrammetric grading system as shown in Figure 4. An electrical signal will be sent to trigger the webcams to grab the images of the FFB at two different fruit locations once the sensors detect the presence of the fruit. The images are then processed by the algorithm which outputs a digital actuating signal to the mechanical sorter. The GUI is designed to allow the user to adjust the threshold value that will distinguish the ripe from the unripe fruits. In total, it will take less than 30 seconds to complete the whole sequences of the photogrammetric grading system, from the feeding to the sorting process. The GUI was developed to offer users two different modes of processing which are off-line and on-line. For the off-line processing mode, the FFB images are manually uploaded by pressing or clicking the 'load image' button. The images are first captured manually, either under controlled environment condition as in the use of an inspection chamber or taken on-site, and saved in a JPEG format. Once the images are uploaded, the photogrammetric grading system will perform automatically. A resize factor function is added in order to reduce the image pixel during the image cropping and hence increase the processing speed.

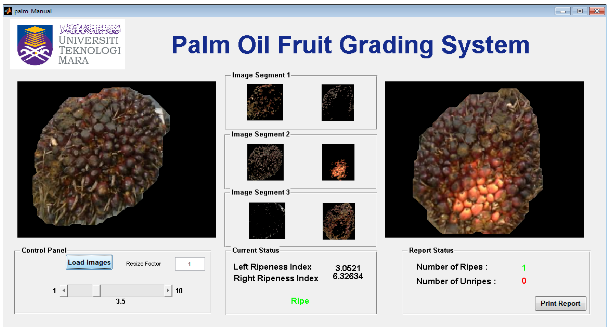

Figure 4. GUI for FFB grading

During the on-line processing, all the photogrammetric sequences are automatically actuated when the presence of the fruit is detected by the sensor which is located at the entrance of the inspection chamber. The on-line processing mode requires the use of a DAQ card to integrate the image processing algorithm to the grading system via the control unit. As compared to the machine vision systems designed by other researchers to grade palm oil fruit, this photogrammetric system provides an on-line inspection and grading without any human intervention and in addition, it is integrated to an automatic fruit sorter unit which is lacking and not available in most systems.

Results and Discussion

For the initial test on the photogrammetric grading system, a total of 34 fruit samples were taken in order to determine the value of the threshold. The attainment of the threshold value will be the predefined value for the system to distinguish the ripe from the unripe fruit values. The testing was done off-line under controlled environment condition and the output values attained after the image processing stage are referred to as the ripeness index. There is a distinct difference in the range of values between the two ripeness categories and the threshold value for this sampling batch is approximately 3.5. FFB samples having greater than ripeness index number of 3.5 will be categorized as ripe and samples with lesser value will be unripe.

Further tests were done to evaluate the overall system's functionality. The next test was to focus on the system's capability to feed the FFB into the inspection chamber for the image acquisition and processing stages, classify the fruits correctly to their ripeness and sort the fruits accordingly. A total of 30 fruit samples of the *tenera* type were taken from a local plantation. The quality of this species may vary slightly from fruits that are harvested in big commercial plantations due to the way the fruits are soiled and irrigated.

Before the test, the fruits were visually graded by the local graders so that the ripeness of the fruits would be known prior to the image analyzing process. From the manual grading process, 20 of the FFB are classified as ripe fruits and the rest are found to be unripe. The ripe fruits are fed into the system continuously followed by the unripe ones. The total weight of the FFB samples is 350 kg with an average of 11.7 kg each and the maximum weight reaching 20.5 kg. The maximum weight is noted for checking on the rollers and conveyor capacity and at the same time the dimensions of the FFB are measured ensuring there is sufficient space for the FFB to be fed and pass through the inspection chamber. The results from the manual grading process are then compared to the output from the photogrammetric grading for each individual fruit.

The ripeness index of the images are recorded and tabulated as in Table 1. The table shows the result for the 30 sample fruits which contain information on the fruit number, ripeness index from camera 1 and 2, average ripeness index number, ripeness category and respective comments. From the results, the graph of the average ripeness index against the fruit sample is plotted and illustrated in Figure 5. The fruit samples which are not correctly graded are highlighted in circles. The threshold value was set to 3.5 and hence the index ripeness values for all ripe fruits should exceed this value. The range of ripe values obtained varies from a minimum value of 3.56 to a maximum of 5.83. Whereas the highest ripeness index for the unripe fruits is 2.49. It can be concluded here that the threshold value of 3.5 can actually be reduced to 3.0 because the highest unripe value will not exceed 2.5 for this particular sampling batch.

Table 1. Ripeness Index Results

Fruit Sample No.	Camera 1 Ripeness Index	Camera 2 Ripeness Index	Average Ripeness Index Number	Ripeness Category (Manual grading)	Status Comment (Automated grading)
1	1.92	2.83	2.38	Unripe	OK
2	2.5	2.48	2.49	Unripe	OK
3	2.21	2.07	2.14	Unripe	OK
4	3.5	3.84	3.67	Unripe	Misclassified
5	2.01	2.56	2.29	Unripe	OK
6	1.99	2.29	2.14	Unripe	OK
7	1.91	2.01	1.96	Unripe	OK
8	2.01	2.60	2.31	Unripe	OK
9	1.68	2.86	2.27	Unripe	OK
10	1.91	2.55	2.23	Unripe	OK
11	5.51	6.14	5.83	Ripe	OK
12	4.64	5.84	5.24	Ripe	OK
13	1.06	7.68	4.37	Ripe	OK but FFB out of webcam range
14	3.65	4.82	4.24	Ripe	OK
15	2.99	5.34	4.17	Ripe	OK
16	2.35	5.04	3.70	Ripe	OK
17	4.42	6.47	5.45	Ripe	OK
18	5.55	9.56	7.56	Ripe	OK
19	3.09	4.45	3.77	Ripe	OK
20	3.16	5.28	4.22	Ripe	OK
21	5.10	10.00	7.55	Ripe	OK
22	3.12	3.99	3.56	Ripe	OK
23	7.05	4.38	5.72	Ripe	OK
24	4.83	3.50	4.17	Ripe	OK
25	-	-	-	-	Technical Error. System hang.
26	2.50	4.69	3.60	Ripe	OK
27	3.38	5.54	4.46	Ripe	OK
28	3.19	4.03	3.61	Ripe	OK
29	2.08	3.20	2.64	Ripe	Misclassified
30	4.98	4.41	4.70	Ripe	OK

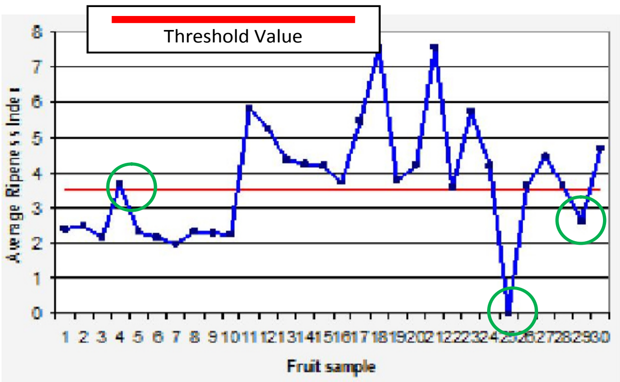

Figure 5. Ripeness index distribution

The same table indicated misclassification occurred for sampling number 4 and 29. Instead of the fruit being unripe and ripe respectively, the results were opposite. For fruit sampling number 4, as referred in Figure 6, it was misclassified because the reddish orange color (ripe side) of the fruit was captured by the webcam and the result given was ripe. If manually inspected, most of the fruit surface was actually ripe and the result from the grading system is actually correct. In order to clarify that the ripeness category processed by the system is correct, the fruit should be manually graded again to avoid confusion. In addition, fruit sample number 29 as shown in Figure 7, also faced similar problem with the purplish black surface color of the fruit exposed and captured by the webcam which resulted in the fruit to be classified as unripe instead of ripe. The best solution would be to rotate the fruit so that all sides can be captured. However, to design the mechanism to rotate may not be easy due to the big sampling number and weight of the fruits.

Another problem faced during the testing process was the difficulty to control the movement of the fruits from the feeder section to the inspection chamber. Manual assistance and human intervention is required for the fruits to be properly aligned so that the fruits are able to roll down, stop and transport to the desired position which is located approximately in the middle of the inspection chamber.

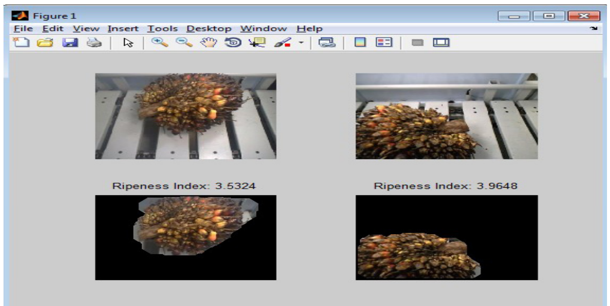

Figure 6. Fruit sample number 4

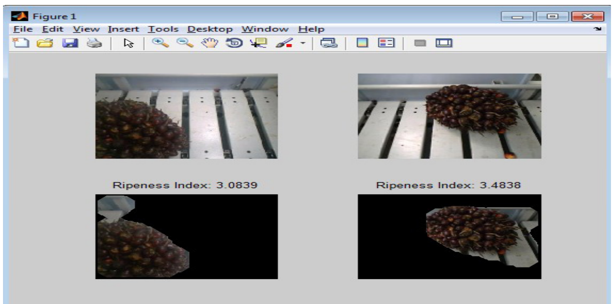

Figure 7. Fruit sample number 29

The case for fruit sampling number 13, where the image of the fruit as captured by the webcam and shown in Figure 8, is a typical case where the fruit position is out of the webcam range. Although only a small portion of the fruit was captured (as highlighted), the computational output was correct because the program was coded not based on the size of the surface area but directly on the RGB values captured. Hence, the rolling movement should be minimized so that the fruit would not land far away from the desired position.

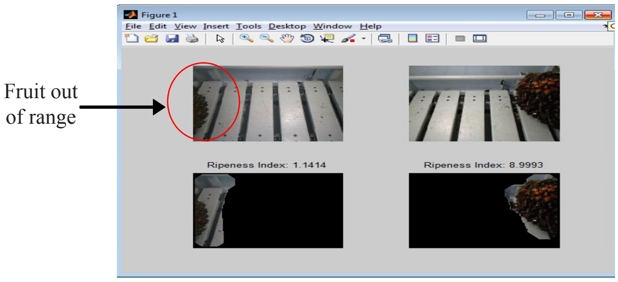

Figure 8. Fruit sample number 13

It can be concluded that there was only two cases of misclassification and another one condition where the data was not computed for that particular sample (fruit sample number 25) due to a technical error that caused the system to hang. The program was interrupted because of the anti-virus scanning process had intervened the processing time. This was immediately corrected by disabling the anti-virus software of the workstation. The system's grading efficiency was calculated to yield 93.1% accuracy. The image acquisition and processing algorithm designed for this photogrammeteric grading system is assured of its accuracy and reliability. The only concern is when the mechanical part of the system is not able to function perfectly as intended. The grading technique applied in this research should also work well for testing other palm oil species and ripeness categories. This can be further extended to carry out on any other harvesting and agricultural products that employ color images as the form of correlation to their ripeness.

Conclusion

A scalable system for an automatic sorting of FFB is presented here and addressing the main quality of the FFB grading classification based on its surface color has proven successfully the working principle behind the photogrammetric grading methodology. The vision system was capable of capturing good quality fruit images, extracting the RGB intensities from the images and correlating them to the ripeness of the fruit bunches accurately. The reliability of the grading and sorting system is above 90% from the testing results achieved and this has proven the feasibility to replace the manual grading tasks at palm oil mills and concurrently increase the efficiency of quality harvesting and grading productivity.

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