An Integral Automation of Industrial Fruit for Grading and Sorting Using Machine Vision

R. Jaafar[1]*, N. Jamil[2], A. Jaffar[1] and C. Y. Low[1]

[1]Faculty of Mechanical Engineering, Universiti Teknologi MARA (UiTM), 40450 Shah Alam, Selangor, Malaysia
[2]Faculty of Information Technology & Quantitative Science, Universiti Teknologi MARA (UiTM), 40450 Shah Alam, Selangor, Malaysia
*E-Mail: roseleena_jaafar@yahoo.com

Summary: At present, the conventional method of grading Fresh Fruit Bunches (FFB) in Malaysia uses a human grader to perform the grading job manually by inspecting the surface color as the main quality attribute. The important manual tasks are to categorize the oil palm FFB into different fruit bunch classification and then sort the fruits. To ensure that consistency and fairness maintained at all times during the manual grading process, an automated grading system using a computer assisted photogrammetric grading methodology to correlate the surface color of FFB to its ripeness is proposed. A mechanical system is designed with a feeder and sorter, integrated to a machine vision system that does the FFB image analysis. The image analysis constitutes of several tasks such as the pre-processing of the fruit images to eliminate the background, image segmentation to classify the images into three segments using K-means clustering and calculation of the average Digital Numbers (DN) for each segment before decision-making is done to classify and sort the fruits. The real-time image acquisition, data acquisition and image processing are programmed in MATLAB® and designed with a Graphical User Interface (GUI). The scalable automated grading cum sorting system was tested and experimental results showed that the digital image grading method generates above 90% accuracy with the sorting system functioning as intended and coordinating well with the computerized imaging system.

Keywords: Fresh Fruit Bunches (ffb), Grading System, Vision System, Image Processing.

1. Introduction

The color of oil palm fruits remains one of the most important factors to determine the grade and quality of the palm oil [1]. As FFB represents the starting input of crude oil palm production, it is, therefore, crucial that only good quality FFB be selected and processed. In order to increase the efficiency and quality of grading FFB in palm oil mills, computer-based technologies such as machine vision has been implemented and tested by researchers by local institutions [2, 3, 4] to replace the traditional grading performed by trained human inspectors. However, most of the existing systems have special architectures, processor board, hardware implementation of special purpose algorithm, etc. Thus, the idea here was to design a system using low cost architecture and standard hardware where possible, and programmed using a user-friendly platform of technical computing language yet maintaining its accuracy and reliability. The proposed system is modular and composed of three units or sections (feeding, inspection and sorting) for easy assembly and repair. These few key design areas have made this integral automated grading and sorting machine different from other available oil palm grading systems.

2. System Overview

The color of many foods has been measured using computer vision techniques [5] and the set-up or the hardware configuration of a vision based machine inspection system is relatively standard. The FFB color vision based machine inspection system comprises of: (1) a feeder unit connected to a conveyor controlled system that delivers FFB to the subsequent station in a systematic manner; (2) a vision inspection system which comprises of a workstation for processing and storing of images, a lighting chamber with an illumination system and two webcams for acquiring of FFB images; (3) a sequence control system using programmable logic controller (PLC) and data acquisition (DAQ) card to integrate the image processing module; and (4) a separator that separates the FFB according to the ripeness classification. A schematic diagram of the integrated automated grading and sorting machine is shown in Figure 1.

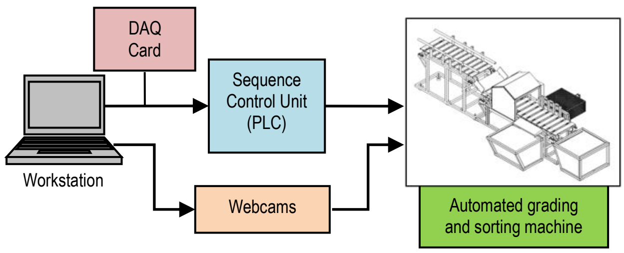

Figure 1. Integrated automated grading and sorting machine.

In order to maintain a complete low cost image processing system, the image capturing and acquiring uses two high-end USB webcams with 2.0 mega pixel (1600 x 1190 pixel) video at 10 frames per second instead of the commonly used expensive digital cameras, frame grabbers and dedicated software system to measure the color of many foods. The computational technique with a combination of a low-cost web cam, image processing software has been used to provide a less expensive and more versatile way to measure food color. In order to facilitate uniform lighting conditions, the webcams are fixed to a special constructed lighting chamber having an entrance and exit opening of approximately 480mm. The inner surface of the lighting chamber is painted white and for illumination purpose, four white 8-watts fluorescent tubes are used. The distance between the webcam and the fruit is approximately 580mm. The set-up of the illumination and inspection chamber are illustrated in Figure 2.

3. Image Analysis

After the FFB images are captured using webcams, the RGB color values are measured using MATLAB® program, which computes the average values for each color value. Industrial vision systems use software that is dedicated and not flexible. Whereas MATLAB® is user friendly and simple computational platform. The assisted photogrammetric grading methodology adopted in this research is depicted in Figure 3. This includes the image acquisition from the illumination system, image pre-processing, image segmentation, grading of the FFB by calculating the colors of the digital numbers and classification of the FFB ripeness into two fruit ripeness categories.

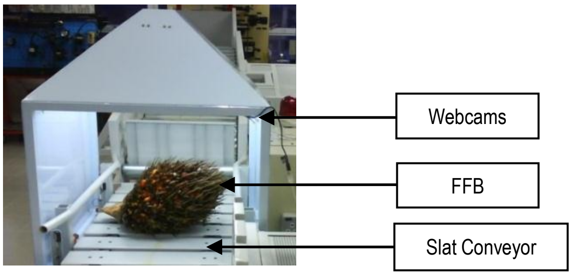

Figure 2. Inspection chamber with lighting and vision system.

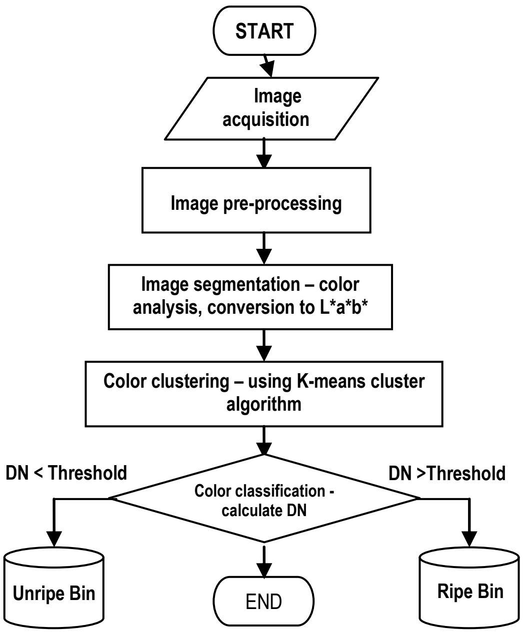

Figure 3. Algorithm flow chart for photogrammetric grading.

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. Image pre-processing, on the other hand, is the next crucial step to eliminate the background from the FFB and accomplished by creating a mask of the original image and performing a product of the mask with the original image. The steps involved in creating the mask after image acquisition are image binarization, morphological operations, properties extraction and cropping. The FFB image was further segmented into separate clusters based on its color by using L*a*b* color model. The L*a*b*, or CIELab, color space is an international standard for color measurements, adopted by the Commission Internationale d'Eclairage (CIE) in 1976. L* is the luminance or lightness component, which ranges from 0 to 100, and parameters a* (from green to red) and b* (from blue to yellow) are the two chromatic components, which range from -120 to 120 [5, 6]. The L*a*b* space is perceptually uniform, i.e., the Euclidean distance between two different colors corresponds approximately to the color difference perceived by the human eye [7]. In order to carry out digital image analysis in food, it is necessary to know the color measure of each pixel on the surface of the food, it is necessary to know the color value of each pixel of its surface. The RGB webcam obtains information in pixels and converting them into L*a*b* units. Using the L*a*b* Color Space and K-means clustering algorithm in MATLAB®, the image can be broken up into several segments and the average color Digital Numbers (DN) values are calculated for each segment to classify the FFB into ripe or unripe category. Snapshots of the processed images are shown in Figure 4.

4. Graphical User Interface

The integration of the image processing algorithms is to develop a Graphical User Interface (GUI) for the photogrammetric grading system as shown in Figure 5. Electrical signals are sent to trigger the webcams to grab the images of the FFB at two different fruit locations once the sensor detects its presence. The images are then processed by the algorithm, which outputs a digital actuating signal to the mechanical sorter. The GUI allows user to adjust the threshold value that will distinguish the ripe from the unripe fruits. Some of the features include two different modes of processing, which are off-line and on-line. For the off-line processing mode, the FFB images are uploaded manually by pressing or clicking the 'load image' button. First, the images are captured either under controlled environment condition as in the use of an inspection chamber or taken on-site which is saved in a JPEG format. Once the images uploaded, the photogrammetric grading system will perform automatically. A resize factor function reduces the image pixel during the image cropping and hence increases the processing speed. The maintenance of production statistics as outputs is also available. Whereas the on-line processing, all the photogrammetric sequences are automatically actuated when the presence of fruit detected by the sensor that is located at the entrance of the inspection chamber. The on-line processing mode requires the use of a DAQ card to integrate the processing image 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 automatic grading and in addition, it is integrated to a sorter unit which is lacking and not incorporated in most available systems.

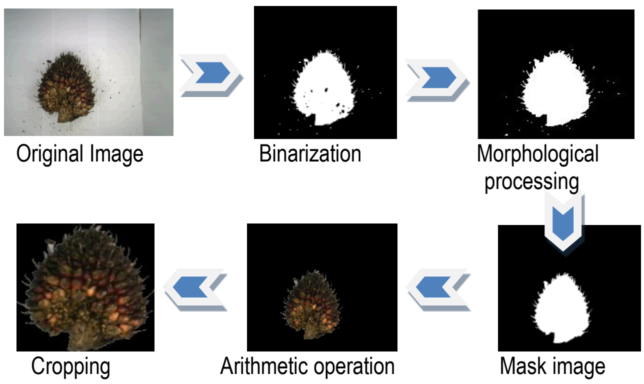

Figure 4. Processed images.

5. System Performance

The threshold value acquired through sampling of 34 fruit samples as the initial test done on the system. The attainment of the threshold value will be the setting value for the system to distinguish the ripe from the unripe fruit values. This test done off-line under controlled environment condition and the output values attained after the image processing stage and known 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 this ripeness index number are categorized as ripe and samples with lesser value will be unripe. Further tests were conducted to evaluate the overall system's functionality.

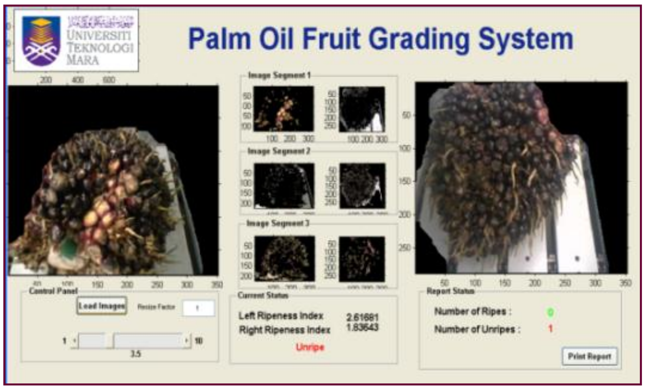

Figure 5. GUI for palm oil fruit grading system.

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. Thirty fruit samples of the *tenera* type were taken from a local plantation. The quality of this species may vary slightly from fruits harvested in big commercial plantations due to the way the fruits are soiled and irrigated. Before the test, local graders at the estate visually graded the quality of the fruits so that the ripeness of the fruits known prior to the image analyzing process. From the manual grading process, 20 of the FFB classified as ripe fruits and the rest found to be unripe. The ripe fruits continuously fed into the system followed by the unripe ones. The total weight of the FFB samples is 350kg with an average of 11.7kg each and the maximum weight reaching 20.5kg. At the same time, checking on the rollers and conveyor, and ensuring the size of the fruit is able to pass through the inspection chamber.

6. Results and Discussion

The ripeness index of the fruit images recorded from the GUI and summarized in Table 1. The table shows the average ripeness indexes for the 30 sample fruits taken from two cameras and the respective ripeness category for each fruit. The threshold value was set to 3.5 and hence the average ripeness index for all ripe fruits should exceed this value. The range of ripe values obtained varied from a minimum value of 3.56 to a maximum of 7.51. Whereas the highest ripeness index for the unripe fruits is 2.49. In conclusion, it is possible to reduce the threshold value of 3.5 to 3.0 because the highest unripe value will not exceed 2.5 for this particular sampling batch.

Table 1. Tests results.

No. of Fruit Samples	Ave. ripeness index range	Ripeness Category	Remark (Between manual and auto system)
9	1.96 – 2.49	Unripe	In agreement
17	3.56– 7.51	Ripe	In agreement
2	-	-	Technical error (data not available)
1	3.67	Ripe	Misclassification
1	2.64	Unripe	

The data from the same table indicated misclassification has occurred for two fruit samples (sampling number 4 and 29). Instead of the fruit being unripe and ripe respectively, the grading results were opposite. For fruit sampling number 4, the reddish orange color representing the 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 was correct. Nevertheless, the fruit was manually graded and reanalyzed again to avoid confusion. The best solution to avoid this problem would be to rotate the fruit and capturing images from all sides. However, to design the mechanism to rotate may not be easy due to the big sampling number and weight of the fruits. It was also difficult to control the movement of the fruits from the feeder section to the inspection chamber due to the fruit size.

7. Conclusion

The FFB is unique in many ways as compared to other types of fruits commonly graded by computerized vision system. The big size and weight of the fruit as well as the non-uniformity of the ripeness color have added great challenges to the development of this system. This has made the image acquisition process as well as the system's mechanical design phase a difficult one. Nevertheless, with several modifications and improvements made have successfully developed a scalable system for an automatic grading and sorting of FFB. This has proven the capability of 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 result of this work yields a system that is able to classify the fruits above 90% accuracy with a maximum time of 28 seconds to complete the whole sequence of the photogrammetric grading system, from the feeding to the sorting process. 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.

Acknowledgement

The authors would like to express their gratitude to the Ministry of Science and Technology, Malaysia (MOSTI) for the financial support given to this work under the eScience Fund (Project Grant No: 05-01-01-SF0118).

References

[1] Malaysian Palm Oil Board (MPOB), 2003, Oil Palm Fruit Grading Manual, Ministry of Primary Industries, Malaysia.

[2] Rashid Shariff, Nor Aizam Adnan, Radzali Mispan. Shattri Mansor, Rohaya Halim, Roop Goyal, 2002, Correlation between Oil Content and DN Values, Department of Biological & Agricultural Engineering, Putra University, Malaysia.

[3] Wan Ishak Wan Ismail, Mohd Zohadie Bardaie and Abdul Malik Abdul Hamid, 2000, Optical Properties for Mechanical Harvesting of Oil Palm FFB, Journal of Oil Palm Research, 12:38-45.

[4] Abdullah, M. Z., Guan, L. C., Lim, K. C., Karim, A. A., 2004, The Applications of Computer Vision System and Tomographic Radar Imaging for Assessing Physical Properties of Food, Journal of Food Engineering, 61/1:125-135.

[5] Papadakis, S. E., Abdul-Malek, S., Kamdem, R. E., Yam, K. L., 2000, A Versatile and Inexpensive Technique for Measuring Color of Foods, Food Technology, 54/12:48-51.

[6] Yam, K. L., Papadakis, S., 2004, A Simple Digital Imaging Method for Measuring and Analyzing Color of Food Surfaces, Journal of Food Engineering, 61:137-142.

[7] Hunt, R. W. G., 1991, Measuring Color, 2nd Edition, Ellis Horwood.