*Maejo Int. J. Sci. Technol.* **2013**, *7*(03), 444-455

*Maejo International Journal of Science and Technology*

**ISSN 1905-7873**
Available online at www.mijst.mju.ac.th

*Full Paper*

# Determining the size and location of longans in bunches by image processing technique

**Chawaroj Jaisin [1], Siwalak Pathaveerat [1, 2,]* and Anupun Terdwongworakul [1, 2]**

[1] Department of Agricultural Engineering, Faculty of Engineering at Kamphaengsaen, Kasetsart University, Kamphaengsaen, Nakhon Pathom 73140, Thailand
[2] The Centre of Excellence for Agricultural and Food Machinery, Kasetsart University, Kamphaengsaen, Nakhon Pathom 73140, Thailand

* Corresponding author, e-mail: fengslp@ku.ac.th

*Received: 14 November 2012 / Accepted: 11 November 2013 / Published: 20 November 2013*

---

**Abstract:** An experimental sorting system was developed for bunches of longan fruits by using an image processing technique. Specifically, a machine-vision system was developed for determining the size and location of individual longans in the bunch. The experimental system involved the use of a camera with a charge coupled device to record images of longan fruits in bunches, which were subsequently converted into digital data using a TV card installed within a microcomputer. The analysis was performed with an image processing software which determined the size and location of each individual longan. The HSB (hue, saturation and brightness) colour model was adapted to the images of longan fruits in bunches, including branches and leaves, to separate the objects of interest from the background. The images of longans were further processed to eliminate noise and convert the images to gray scale while a Canny edge detector was operated as an image processing tool to detect edges in the images of longan fruits. Since the shape of longans is roughly circular, a circular Hough transform was also applied to the images in searching for longans. The results show that the overall margin of error of the size determination using the developed image processing technique, as compared to actual sizes of longan fruits, was less than 10%. In addition, the aforementioned image technique could locate 90% of individual longans which were not overlapped and detect 79% of the overlapped longan fruit in the images.

**Keywords:** image processing, longan, sorting system, circular Hough transform

---

**INTRODUCTION**

Longan (*Dimocarpus longan* Lour., *Euphoria longana* Lamk. or *Nephelium longana* Camb.) is considered one of the most popular fruits in Thailand. Fresh longan contains 81% water, 17% carbohydrate and 1% protein [1], and provides an assortment of nutrients such as glucose, sucrose, fructose and vitamins C, B1 and B2 [1, 2]. In Thailand, there are two kinds of longan products: fresh longan and processed longan (dried longan and freeze-dried longan). In 2012, Thailand exported more than 600,000 tons of fresh and processed longan, with a total value exceeding US$650 million [3].

One of the most important postharvest operations is quality evaluation, in which fruits are sorted based on size, colour, degree of maturity, shape, and defect. Such an operation requires several parameters to be quickly identified and managed at the same time. The efficiency and effectiveness of sorting governs the quality standard of the product, which in turn determines its marketability [4]. Accordingly, there is a need for a robust, consistent, rapid and cost-effective sorting method.

One of the major postharvest operations for longan is size sorting and trimming of fruits in bunches. While the sizing of fresh longan is customarily done by either diameter sizing or weight sizing [5], Thai agriculturists have a preference for diameter sizing in grading whole bunches of fresh longan [6]. This operation is currently done by hand as follows [6]. A sorter picks up a single branch containing about 10 fruits and visually inspects them to determine the size. If undersized fruits are detected, the fruit size is checked with a circular template and the undersized fruits trimmed off. Each branch is graded based on the size of the majority of the fruits in the branch. The sorter then combines roughly 10 sorted branches to form a large bunch weighing approximately 1 kg. This sizing and trimming operation is time-consuming, labour-intensive, inconsistent and requires expert sorters. Therefore, it would be desirable to develop an automatic sorting and trimming machine to perform such operation. The first step in developing such a machine is to develop a system that can determine the size and location of longans in a small bunch on a single branch.

Machine-vision is an electro-optical technique that can be used to determine the size and location of multiple objects. In this technique, the reflectance characteristic of a product illuminated by a light source can be determined using a visible-wavelength camera equipped with a charge coupled device (CCD) which assesses the image by either an area-scan or a line-scan. Various image processing techniques have been used to determine the size, location, and shape of objects. In agricultural applications, several researchers have used the machine-vision technique to locate fruits on trees.

Jiménez *et al.* [7] presented a comprehensive review of various machine-vision techniques used by a number of researchers to locate fruits on trees in orchards. Slaughter and Harrel [8] developed a classification model that used only colour information in a digital colour image to discriminate oranges from the natural background of an orange grove. Zhao *et al.* [9] presented methods of locating both red and green apples in cluttered environments on a single- image frame. They presented a procedure and selected textural properties and redness as the image processing tool for locating apples in an image. Vaysse *et al.* [10] presented a method for determining the size and colour of fruits in shipping bins. Computation of the gradient of luminance in a colour image was used to determine a geometrical model. They applied the technique to apples and were successful in estimating the size of the fruits with only 10% false detection.

Whittaker *et al.* [11] used circular Hough transform (CHT) to locate and identify tomatoes in an image that had been acquired under natural field conditions. Using a modified CHT method, they were able to locate tomatoes based on shape and not colour, even when the scenes contained substantial background noise. In another example, Rizon *et al.* [12] applied the separability filter and CHT technique to identify circular-shaped objects in a noisy and cluttered image.

The problem of determining the size and location of longan fruits in bunches is somewhat different from that for other kinds of fruits on trees in natural settings, where there is usually a greater extent of noise, lighting variation and interfering objects in the background. Longan fruits and branches are a highly uniform light brown colour and, fortunately, longan is fairly circular-shaped. Thus, image processing and CHT technique can be utilised for sizing and locating longans in bunches. Briefly, this study aims to develop a practical and much-needed method for determining the sizes and locations of longans in a bunch. Although the method is based on known image processing techniques, the information gained would be very useful for further development of automatic sorting and packaging (bunching) of longan for export. The results should include less time used for sorting, greater accuracy of size and improved competitiveness in the global marketplace.

## MATERIALS AND METHODS

### Hardware

The system consisted of a CCD camera (VCC-4795PE, Sanyo), which was mounted in front of a controlled light box at a distance of 35-50 cm from the target. The CCD provided a resolution of 540 horizontal TV lines. Three 14W fluorescent energy-saving lamps (Essential model, CDL E27, 220-240V, 1CT, Philips) with reflective covers were mounted on three sides of the box (top, left and right) to provide a uniform light intensity with minimal shadows. The interior surfaces of the controlled light box were covered with white fabric, except the background, which was covered with black fabric. The CCD captured the image when the frame grabber (FlyTV-34FM Tuner PCI, LifeView) commanded and returned image signals to the frame grabber. The image signals were converted into digital signals by the frame grabber. Next, the digital image signals were sent to a microcomputer for analysis (Figure 1). The digital image was constructed using an AMD Sempron 2200+ processor with a clock speed of 1.8 GHz and 768MB RAM with a clock speed of 400 MHz. The operating system was Microsoft Windows XP. The image was fed into the light box controller and the whole longan bunch was evaluated. The grade of each bunch was defined using three indicators: AA grade, A grade and B grade.

### Software

The analysis was performed with a developed image-processing software. The computer programme was written for a specific application in locating each longan and determining its size. Figure 2 shows the entire processing procedure. The first step was to obtain the input image of a bunch of longans in RGB (red, green, blue) colours with a resolution of 640 × 480 pixels at 96 dpi (Figure 3). The image was acquired by the CCD camera and the digital data of the image were obtained by the frame grabber. The image consisted of longans, foliage and branches, but only the longans were of interest. The next step was therefore to eliminate the foliage and branches as much

*Maejo Int. J. Sci. Technol.* **2013**, *7*(03), 444-455

as possible. The foliage can be eliminated from the image by using the colour threshold. HSB (hue, saturation and brightness) thresholding was chosen as the tool to eliminate the foliage in the image because the difference between green foliage and brown longans is relatively strong. The threshold value was calculated using iterative threshold selection [13].

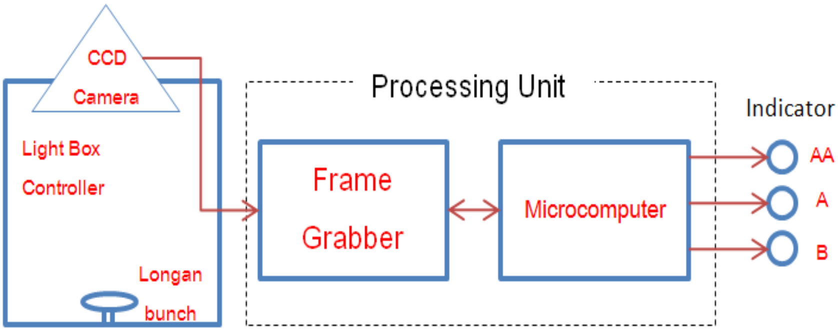



**Figure 1.** Experimental diagram for longan evaluation system

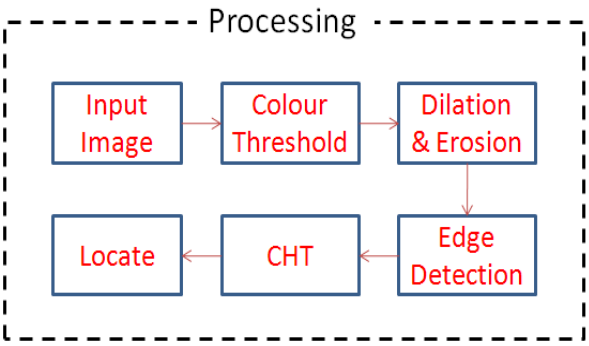


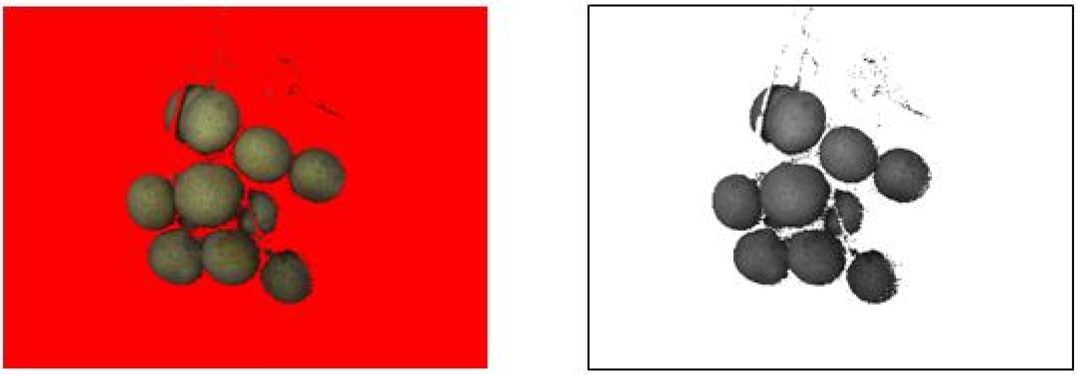

**Figure 2.** Block diagram of image processing steps

**Figure 3.** Longans in bunch with leaves and branches

Figure 4(a) shows the image after the green leaves have been removed by colour thresholding. It is more difficult to eliminate the branches by colour thresholding because the colour of the brown branches is not much different from that of the longans. However, due to the prominent difference in thickness between the branches and the longans, the technique of dilation and erosion can be used to solve this problem. In this process, the image was first converted into a grayscale

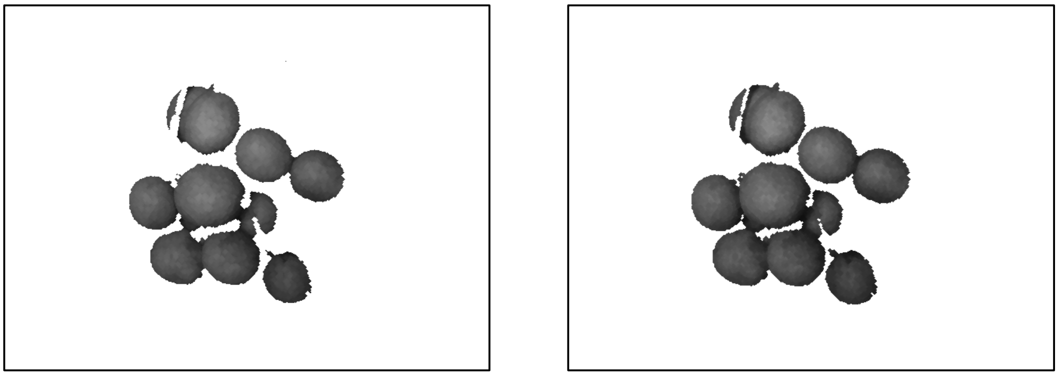
*Maejo Int. J. Sci. Technol.* **2013**, *7*(03), 444-455

image (Figure 4(b)). Then a thin erosion process [14] was performed to erode away the thin branches (Figure 5(a)). Since the erosion process also eroded away the perimeters of the longans, it was necessary to perform a dilation process [14] to restore the previous size of the longans (Figure 5(b)) before commencing the next procedure.



(a) (b)

**Figure 4.** Image of longans: (a) without green leaves; (b) without leaves in grayscale



(a) (b)

**Figure 5.** Image of longans: (a) after thin erosion process; (b) with restored size after dilation process

The next step was edge detection. The purpose of edge detection in general is to significantly reduce the amount of data in an image while preserving the structural properties to be used for further image processing. The Canny edge detection algorithm [15] was selected because it is one of the most commonly used image processing tools that detect edges in a very robust manner. Applying the Canny edge detection algorithm to the grayscale image of longans in Figure 5(b) resulted in an image containing only the edges of the fruit (Figure 6). Then the resolution of the edge image was reduced to 160 × 120 pixels in order to minimise the processing time in the next step. The CHT technique was then used to determine the location and size of each longan from the edges. A brief description of the CHT technique is provided below.

*Maejo Int. J. Sci. Technol.* **2013**, *7*(03), 444-455

.

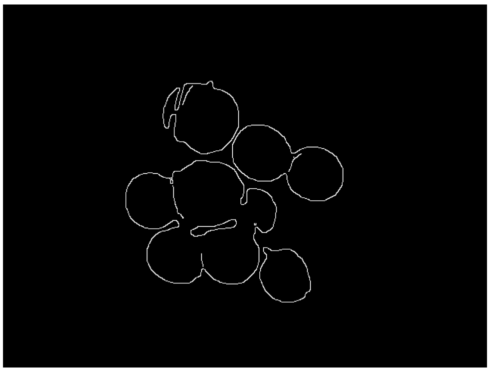


**Figure 6.** Image of only the edges of longans

In Figure 6, which is the edge image, a circle with a chosen radius was drawn at each edge point with the centre at that edge point. A circle with radius R and centre of pseudo circle (a, b) was described with the parametric equations (1) and (2) [16, 17]:

$$x = a + R\cos\theta \tag{1}$$

$$y = b + R\sin\theta \tag{2}$$

where x and y are coordinates on a two-dimensional matrix and θ is the angle that sweeps through the full 360-degree range. An example of the CHT is demonstrated in Figure 7; each point in the geometric space (left) generates a circle in the parameter space (right). At any coordinates where the perimeter of the drawn circle passes through, the frequency of occurrence is incremented in an accumulator matrix which has the same size as the parameter space. The accumulator contains numbers corresponding to the number of circles passing through the individual coordinates (xn, yn). Thus, the highest numbers correspond to the centres of the circles in the image. For example, if there is a circle with radius R1 and centre (x1, y1) in the image, the CHT algorithm that draws circles with radius R1 will give the highest number of occurrences at (x1, y1) because all the circles drawn with centres on the perimeter of that circle will intersect at (x1, y1). The centres of the circles were obtained by means of thresholding the values at individual points in the accumulator matrix.

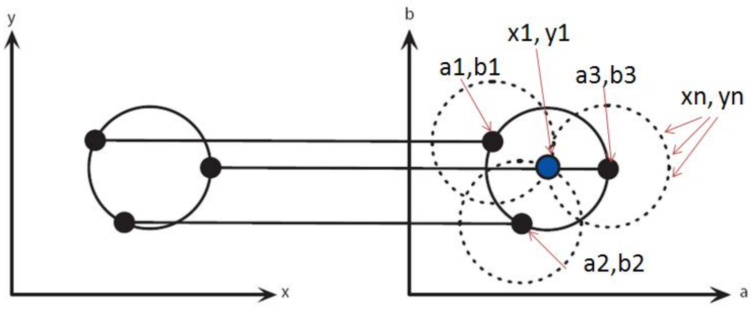


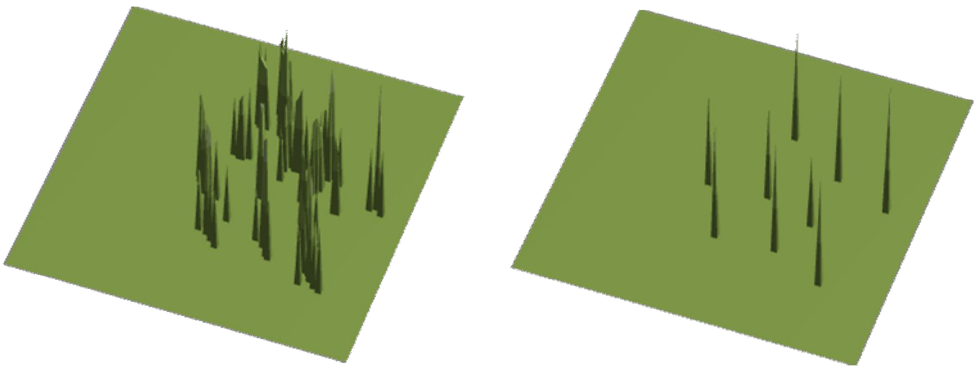

**Figure 7.** A CHT from the x,y-space (left) to the parameter space (right)

In an image of a fruit bunch (Figure 6), the circles may not intersect exactly at the centre, resulting in groups of high-value points that represent candidates for the centres. The following thresholding procedure was developed to locate the centres. The thresholding of values in the accumulator matrix was performed by first finding the maximum value in the matrix and then removing all the values in the matrix that were below 0.6 of the maximum (Figure 8(a)). Then the

*Maejo Int. J. Sci. Technol.* **2013**, *7*(03), 444-455

average of the values of the remaining points was calculated and all the remaining points with values below the average value were eliminated. This process resulted in a number of small groups of high-value points. The point with the maximum value in each group was selected as the candidate for the centre of the circle (fruit). The last step was to check each point by drawing the corresponding circle and checking the colour (hue value) of each pixel in the circle to determine if the majority of the pixels matched the colour of the fruit (Figure 8(b)).

In an image where there were circles of different radii such as an image of longans with different sizes, the CHT would be performed repeatedly with a different radius each time. In the case of longans, the range of size is known, i.e. between 15-35 mm. Therefore the CHT was performed from the minimum radius ($R_{min}$) to the maximum ($R_{max}$) with one-pixel increments. At the end of the iterations, the centres of all the circles with radii within the range of $R_{min}$ and $R_{max}$ would be found. Knowing the location of each centre and its corresponding radius, the circles could be mapped on the original image (Figure 9).



(a) (b)

**Figure 8.** Surface plots of: (a) all candidates for the centre of each longan in a bunch; (b) true centre of each longan in a bunch

**Figure 9.** Locations and sizes of longans (circles) found by CHT

ImageJ software [18] was used to perform the first few steps of the image processing up to the end of Canny edge detection. A separate software programme was developed using Borland C++ Builder 5.0 [19] to perform the CHT, the procedure to identify the fruit centres and to draw the circles on the image. The total time to complete the process, starting from inputting the edge line information to the completion of drawing the circles on the image, was approximately 1 sec. This processing speed, even with a personal computer, is acceptable for online sorting of fruit bunches.

**Evaluation of the System**

The above image processing system was evaluated by processing a total of 140 images of longan bunches. In these images, 997 longans were observed with 658 longans seen as whole fruits (not overlapped) and the remaining partially seen (overlapped). The evaluation was divided into three parts as follows.

*Accuracy evaluation of detection of individual fruits in bunch*

The system was first evaluated for the ability to detect the individual fruits in a bunch for all images. The performance of the system was tested separately for accuracy in detecting only longans that appeared as whole fruits and those seen as partly overlapped fruits. The overall accuracy was a combination of both performance results.

*Evaluation of the accuracy of size determination*

A calibration equation was built by regression analysis and used in the determination of the actual size or diameter of individual longans from the measured size in the images. A description of the regression model is as follows. The CCD camera was mounted on an adjustable-length stand. A piece of circular paper was placed on the platform opposite the camera and in the line of sight of the camera lens. The camera was mounted 45 cm away from the paper. The image of the paper was taken, processed and recorded three times. This procedure was repeated for paper sizes of 2.5, 2.8, 3.0, 3.2, 3.5 and 4.0 cm in diameter. The obtained values were constructed as linear equations using Microsoft Excel. The actual size (cm) of the circular paper was submitted as an independent variable and the size measured from the image (pixel) as a dependent variable in the regression analysis. The obtained equation was used to convert the size of the fruit in the image into a determined size, which is the fruit diameter determined by the machine-vision system.

The overall accuracy of size measurement of a group of longans is defined as shown in equation (3):

$$\text{Overall accuracy (\%)} = \frac{100}{n}\sum_{i=1}^{n}\frac{Dd_i}{Dt_i} \tag{3}$$

where $n$ is the number of longans, and $Dd_i$ and $Dt_i$ are the determined and true diameters of the $i^{\text{th}}$ fruit respectively. The evaluation of the size determination was also performed separately for whole fruit and partially seen fruit in the images.

*Evaluation of sorting performance based on average fruit size in bunch*

Commercially, longans in a bunch command a higher price than individual longans. The National Bureau of Thai Agricultural Commodity and Food Standards [4] classifies longan in a bunch into five grades by counting the number of fruits per a unit weight, for example fewer than 85 fruits/kg being 1st grade and 85-94 fruits/kg being 2nd grade. The local merchants, however, prefer to measure the diameter because it is easier and faster. The local marketing system classifies longan into three sizes, AA, A and B, for commercial marketing purpose. The AA size is the largest with an average diameter of more than 31 mm. Size A is between 27-31 mm and size B is less than 27 mm [5]. So in practice longan is sorted based on visual inspection of each bunch and the longan size that outnumbers other sizes will represent the bunch grade. Therefore, the third part of the performance test was to evaluate the ability of the system to grade bunches of longan as compared with manual sorting by an experienced sorter.

Each bunch (or image) of longan was first pre-sorted by an experienced sorter into one of three grades (AA, A or B), which refer to the sizes used in current commercial marketing practices. For example, a bunch of longan was judged as grade AA when most of the individual longans were of grade AA. Then they were sorted using the machine-vision system, by which individual fruits (both whole fruits and partially seen fruits) in the bunch were determined for their size and number. The number of correctly sorted bunches was recorded and evaluated for the overall sorting performance by the weight purity index ($P_w$), as shown in equation (4) [20]:

$$P_w = \sum_i P_{gi} W_i \qquad (4)$$

where $P_{gi}$ is the fraction of correct bunches in grade $i$ and $W_i$ is the weight function of grade $i$. In this case, $W_i$ was given the highest weight for grade AA, as the price of this grade is highest. Grades A and B were assigned less weight in descending order.

## RESULTS AND DISCUSSION

### Accuracy Evaluation of Individual Fruit Detection in Bunch

The accuracy of individual fruit detection in the images is shown in Table 1. The image processing system could detect 576 out of 658, or 87.5%, of the longans that were not overlapped. The overlapped fruits could be detected in 211 out of 339 cases, or 62.2%. The overall accuracy of detection was 787 out of 997, or 78.9%. This is expected because the overlapped fruits had only partial edge lines. Thus, in the CHT process fewer circles were drawn from each edge line of the overlapped fruit than those drawn from the longer edge line of the whole fruit. As a result, the number of circles passing through the centre (recorded in the accumulator matrix) could, in some cases, be lower than the threshold level and therefore left out in the process of finding the centre from the accumulator matrix.

**Table 1.** Accuracy of detection of longans in images

| Condition | Longans in images | Longans found | Accuracy (%) |
|---|---|---|---|
| Not overlapped | 658 | 576 | 87.5 |
| Overlapped | 339 | 211 | 62.2 |
| Overall | 997 | 787 | 78.9 |

**Evaluation of Accuracy of Size Determination**

The readable pixels were estimated by the developed software (Borland C++ Builder 5.0) and converted into a determined size (mm), with the calibration equation obtained by regression analysis at $R^2 = 0.989$ as shown in equation (5):

$$X = \frac{Y + 8.658}{7.523} \tag{5}$$

where $X$ is the predicted diameter (mm) of each longan and $Y$ is the number of readable pixels of each longan from the machine-vision system.

The average percentage of accuracy of size determination, compared with the actual size of each longan, is shown in Table 2. Fruits were sorted into three size-grades according to commercial marketing practices in Thailand: AA (diameter greater than 31 mm), A (diameter between 27-31 mm) and B (diameter less than 27 mm). The percentages of accuracy (above 89%) for all cases indicate that the system can be used to determine the size of longan in relation to their actual size.

**Table 2.** Accuracy of size determination of longans in images

| Condition | Size | | |
|---|---|---|---|
| | AA | A | B |
| Not overlapped | 96.3% | 96.0% | 91.8% |
| Overlapped | 92.0% | 93.3% | 89.3% |
| Overall | 92.7% | 95.6% | 90.7% |

Note: AA = diameter >31 mm; A = diameter 27-31 mm; B = diameter <27 mm

**Evaluation of Sorting Performance Based on Average Size in Bunch**

The logans were sorted into three bunch-grades, i.e. AA, A and B. The sorting performance was estimated by the weight purity index. The weight function ($W_i$) was defined by the market values, yielding (depending on the price of each grade) 0.5, 0.3 and 0.2 for AA, A and B sizes respectively. In this experiment, 140 bunches of longan were fed into the system to be sorted into three bunch-grades. The system could correctly sort 40 bunches out of 59 bunches of AA-grade bunch, while for A and B bunch-grades, the system could correctly sort 50 out of 66 bunches and 12 out 15 bunches respectively. The total number of correctly sorted bunches was 102 out of 140. The ratio of correctly sorted bunches to the number of bunches in each grade was calculated as a fraction of correctly sorted bunches ($P_{gi}$). $P_{gi}$ and $W_i$ were then used to calculate the weight purity index ($P_{wi}$) to represent the performance of the sorting system for each grade. The results are shown in Table 3. The total weight purity index of the system is equal to 0.726, i.e. the performance of the sorting system is 72.6%.

**Table 3.** Performance of sorting system of longan in bunches

| Variable | Size | | | Total |
|---|---|---|---|---|
| | AA | A | B | |
| Correctly sorted bunches | 40 (59)* | 50 (66)* | 12 (15)* | 102 (140)* |
| $P_{gi}$ | 0.678 | 0.757 | 0.8 | - |
| $W_i$ | 0.5 | 0.3 | 0.2 | 1.0 |
| $P_{wi}$ | 0.339 | 0.227 | 0.160 | 0.726 |

Note: $P_{gi}$= fraction of correctly sorted bunches in grade i; $W_i$= weight function of bunch in grade I; $P_{wi}$ = weight purity index of grade i
* The number in parentheses represents the total number of bunches in each grade

## CONCLUSIONS

An image processing technique has been developed to locate the position and determine the size of longans in a bunch. The circular Hough transform algorithm works well for determining the centre of longan in the image with acceptable accuracy for the number of fruits detected and the size estimation. The processing time is only around 1 sec, which is acceptable for a real-time sorting and trimming operation. This technique should be useful for future development of an on-line size sorting and trimming system for longan in bunches.

## ACKNOWLEDGEMENTS

This research grant was supported by the programme of Strategic Scholarships for Frontier Research Network for the Joint Ph.D. Programme for Thai Doctoral Degree from the Office of the Higher Education Commission (Thailand). The authors would also like to express their gratitude for the financial support received from the Postgraduate Education and Research Development Project in Postharvest Technology at Chiang Mai University, the Graduate School at Kasetsart University, and the Postharvest Technology Innovation Centre (PHTIC). All authors would like to dedicate the success of this work to the late Professor Bundit Jarimopas.

## REFERENCES

1. Office of Agricultural Extension and Development Region 6, Ministry of Agriculture and Cooperatives, “Longan nutrition”, **2010**, http://www.ndoae.doae.go.th/article2010/longan/longan_nutrition.html (Accessed: October 2013).
2. R. E. Paull and N. J. Chen, “Changes in longan and rambutan during postharvest storage”, *Hort. Sci.*, **1987**, *22*, 1303-1304.
3. Office of Agricultural Economics, Ministry of Agriculture and Cooperatives, “Agricultural import export”, **2013**, http://www.oae.go.th/oae_report/export_import/export_result.php (Accessed: June 2013).
4. National Bureau of Thai Agricultural Commodity and Food Standards (ACFS), Ministry of Agriculture and Cooperatives, “Agricultural Standards Act”, **2008**, http://www.acfs.go.th/km/download/AGRICULTURAL_STANDARDS_ACT.pdf (Accessed: June 2013).

*Maejo Int. J. Sci. Technol.* **2013**, *7*(03), 444-455


5. National Bureau of Thai Agricultural Commodity and Food Standards, Ministry of Agriculture and Cooperatives, “Longans”, **2003**, http://www.acfs.go.th/standard/download/eng/longans.pdf (Accessed: June 2013).
6. B. Jarimopas, K. Boonyapen and W. Hongsiri, “The study on arrangement of the longan fruit in bunch on relation to the standard sorting and packaging”, Proceedings of 5th TSAE National Conference, **2004**, Bangkok, Thailand, pp.308-314.
7. A. R. Jiménez, R. Ceres and J. L. Pons, “A survey of computer vision methods for locating fruit on trees”, *Trans. ASAE*, **2000**, *43*, 1911-1920.
8. D. C. Slaughter and R. C. Harrell, “Discriminating fruit for robotic harvest using color in natural outdoor scenes”, *Trans. ASAE*, **1989**, *32*, 757-763.
9. J. Zhao, J. Tow and J. Katupitiya, “On-tree fruit recognition using texture properties and color data”, Proceedings of IEEE/RSJ International Conference on Intelligent Robots and Systems, **2005**, Alberta, Canada, pp.263-268.
10. P. Vaysse, G. Grenier, O. Lavialle, G. Henry, G. Khay-Ibbat, C. Germain and J. P. Da Costa, “Image processing as a tool for quality assessment of fruits in bulk shipping bins”, Proceedings of Information and Technology for Sustainable Fruit and Vegetable Production, **2005**, Montpellier, France, pp.381-388.
11. D. Whittaker, G. E. Miles, O. R. Mitchell and L. D. Gaultney, “Fruit location in a partially occluded image”, *Trans. ASABE*, **1987**, *30*, 591-596.
12. M. Rizon, H. Yazid, P. Saad, A. Y. M. Shakaff, A. R. Saad, M. Sugisaka, S. Yaacob, M. R. Mamat and M. Karthigayan, “Object detection using circular Hough transform”, *Am. J. Appl. Sci.*, **2005**, *2*, 1606-1609.
13. M. Sonka, V. Hlavac and R. Boyle, “Image Processing: Analysis and Machine Vision”, 2nd Edn., PWS Publishing, Pacific Grove (CA), **1998**, pp.127-130.
14. R. C. Gonzalez and R. E. Woods, “Digital Image Processing”, 2nd Edn., Prentice Hall, Upper Saddle River (NJ), **2002**, pp.523-528.
15. J. F. Canny, “A computational approach to edge detection”, *IEEE Trans. Pattern Anal. Mach. Intell.*, **1986**, *8*, 679-698.
16. N. Jain and N. Jain, “Coin recognition using circular Hough transform”, *Int. J. Electron. Commun. Comput. Technol.*, **2012**, *2*, 101-104.
17. S. Liangwongsan, B. Marungsri, R. Oonsivilai and A. Oonsivilai, “Extracted circle Hough transform and circle defect detection algorithm”, *World Acad. Sci. Eng. Technol.*, **2011**, *60*, 432-437.
18. M. D. Abramoff, P. J. Magalhães and S. J. Ram, “Image Processing with ImageJ”, *Biophotonics Int.*, **2004**, *11*, 36-42.
19. J. Hollingworth, D. Butterfield, B. Swart and J. Allsop, “C++ Builder 5 Developer’s Guide”, SAMS Publishing, Indianapolis (IN), **2000**, pp.1472-1489.
20. K. Peleg, “Produce Handling, Packaging and Distribution”, AVI Publications, Westport (CT), **1985**, p.567.