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Image-based lime size grading using the comparison ratio of the pixel radius and the actual size of lime fruit

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ABSTRACT

Lime is a commercially important fruit in Thailand whose sale price depends on the fruit's size; hence, farmers must grade limes by size before distribution. However, as lime grading machines are very expensive and each province has different size grading limits, grading is often performed manually, which is time-consuming and error-prone. Agricultural production systems for automatic selection and grading use image processing techniques for extracting key features. Therefore, this study proposes techniques to extract features of limes and to develop analytical methods for grading them. This method can reduce time and cost, and increase accuracy and flexibility for selecting different lime sizes according to each province's size criteria. To verify our method, we classified limes according to criteria from four Thailand provinces as sample data in an experiment. The focal image feature was the radius or diameter of the lime and the grading conditions were defined by the maximum comparison ratio of the fruit's radius in pixels to the measured radius of the actual lime in centimeters. The average grading accuracy was 99.59%, which outperformed that of mechanical grading. The processing time was 1.70 seconds per individual fruit.

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1. INTRODUCTION

The lime is a key crop in Thailand that is grown in all provinces [1]. Farmers need to classify harvested limes by size before sale because the price is size-dependent. Sorting machines are expensive and lack the flexibility to classify different lime sizes according each province's standards. However, manual sorting is inefficient, error-prone, and time-consuming. Image processing techniques can be applied to agricultural products to reduce both machine cost and human error. Previous applications have included plant quality classification [2], [3], plant disease detection [4]-[6], and monitoring of plant growth [7], [8].

Image processing techniques for automatic quality classification of agricultural products are determined by their geometry and properties such as size, shape, color, ripeness, volume, bruising, disease and rot [9]-[11]. Leaf area analysis [12] uses the ratio of leaf green pixels to the red pixel region as a reference, which can reduce computing time for calculation but requires a reference region. Grape weight calculation was used to predict the quantity of wine [13] using the Canny algorithm and logarithmic function to detect grape shape. In addition, the Hough transform was used to detect the grape [14]. Banana ripeness was analyzed by applying image processing using color histogram means, perimeter, area, and major and minor axes of the fruit's boundary image [15]. Image processing techniques were also used to estimate the volume of oranges and limes, which could be calculated from the partial geometry of the pyramid of an image captured by two cameras [16]. A previous study [17] proposed a method for classifying mangoes into three sizes (large, medium, and small) using the main characteristics of projected area, perimeter and roundness of the fruit's image. Similarly, strawberries were classified using shape, color, and size: the k-means algorithm was used to classify the shape based on the perimeter, colors were extracted with the dominant color of color a* in the color model L*a*b*, and size was detected using maximum diameter. This method classified strawberries into three shapes: long, square, and round [18]. Behera *et al.* [19] proposed the picture handling parameters, for example, major axis, minor axis, bounding box, perimeter & diameter to grading of tomatoes. The quality evaluation of pomegranate fruits [20] are classified using the total area of pomegranate fruit that extract by image processing. While most image-based classification of fruits extracts key features from the aforementioned geometric characteristics, most classification of limes has to date been based on the number of pixels in an image of lime area [21], although Khojastehnazhand *et al.* [22] developed an image processing technique to estimate lime diameter and area using two CCD cameras.

In the past years, research has been limited in its power to classify agricultural products because of methods that were developed for only certain sizes of classification. In addition, these methods cannot be used to extract features of differently-sized limes according to different regional criteria. Therefore, the aim of this research is to apply image processing to analyze different lime sizes by each Thailand province's size criteria to improve accuracy and reduce the cost of automated grading.

2. RESEARCH METHOD

Both manual and mechanical lime grading classify limes by size based on differences in diameter. Therefore, this study proposes image processing techniques to extract the diameters of each fruit in an image. Figure 1 shows diameters depth (A), height (B), and width (C) for an individual fruit.

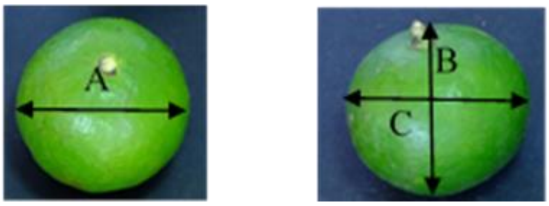

Figure 1. The diameters of each lime fruit

2.1. Lime image data set

Limes were collected from a sample of approximately 1500 fruits, each roughly 3 to 6 centimeters in size. To obtain precise, high-resolution measurements of each fruit's height, width, and depth, we used a digital vernier caliper and captured images of each dimension, as shown in Figure 2. All measurements were made to millimeter resolution.

Figure 2. Measurement of a lime with a digital vernier caliper

Collected images of sampled limes were captured for two sides of each lime: top and side. We captured images of 10–20 limes per shot, with the same distance between the captured limes and the camera. The distance between each lime was at least 0.5 centimeters. The camera was placed 100 centimeters above the ground and angled at 90 degrees, with a black background and the same lighting as shown in Figure 3. Example images of captured limes are shown in Figure 4. We classified lime fruit sizes according to the size criteria of four Thailand provinces as shown in Table 1.

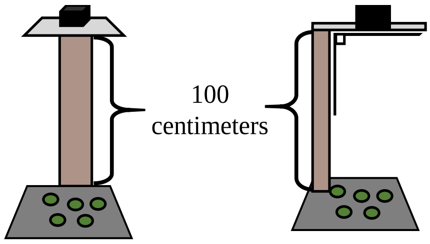

Figure 3. Camera setup for image capture

Figure 4. Captured lime images

Table 1. Size criteria of four Thailand provinces

Size class	Province			
	Phetchaburi	Phichit	Kamphangphet	Tak
1	$d > 4.5$ cm	$d > 4.5$ cm	$d > 5.2$ cm	$d > 5.2$ cm
2	$4.3 < d \leq 4.5$ cm	$4.2 < d \leq 4.5$ cm	$5.0 < d \leq 5.2$ cm	$5.0 < d \leq 5.2$ cm
3	$3.5 \leq d \leq 4.3$ cm	$4.0 < d \leq 4.2$ cm	$4.8 < d \leq 5.0$ cm	$4.8 < d \leq 5.0$ cm
4	N/A	$3.7 < d \leq 4.0$ cm	$4.6 < d \leq 4.8$ cm	$4.4 < d \leq 4.8$ cm
5	N/A	$3.4 \leq d \leq 3.7$ cm	$4.4 < d \leq 4.6$ cm	$4.2 < d \leq 4.4$ cm
6	N/A	$d < 3.4$ cm	$4.1 < d \leq 4.4$ cm	$3.8 \leq d \leq 4.2$ cm
7	N/A	N/A	$3.8 \leq d \leq 4.1$ cm	$d < 3.8$ cm
8	N/A	N/A	$d < 3.8$ cm	N/A

2.2. Framework of lime size grading

The aim of this study is to develop a technique to extract the geometric features and shape of limes, and design an analytical process using the extracted features to grade lime fruit sizes, with the goals of improving accuracy and reducing time and labor for grading. Figure 5 shows the framework of this study, with a division into two main steps: learning phase and grading phase.

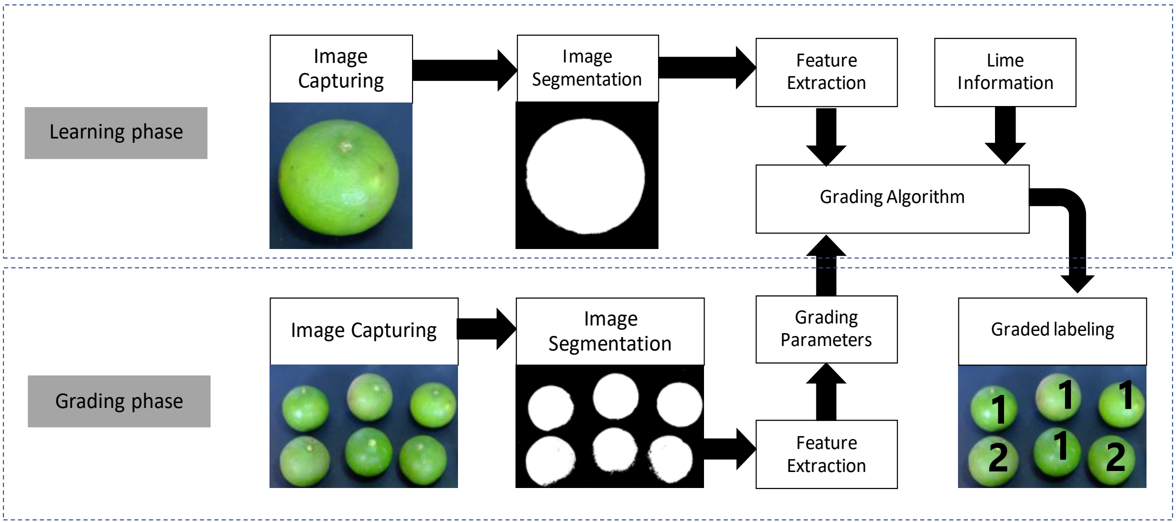

Figure 5. Framework of image-based lime size grading method

2.2.1. Learning phase
The learning phase is the procedure for developing and training the lime size grading algorithm. The algorithm is generated using geometric and shape features extracted from the diameter of each lime's size. The learning phase includes the following steps.
- Step 1: Grayscale image conversion using a thresholding algorithm [23], [24]. The result of the grayscale image conversion is dependent on threshold values of image intensity as shown in Figure 6.
- Step 2: Edge detection. Each lime fruit's edges are detected using the Canny algorithm as shown in Figure 7, [25], [26].
- Step 3: Image segmentation using separate regions of each lime fruit and background with a region-growing method as shown in Figure 8, [27], [28].
- Step 4: Feature extraction. Diameters measured in pixels are extracted from each fruit's image, representing shape and geometric properties. This process detects the centroid of a fruit's edge in the image and calculates major and minor axes that correspond to the pixel-based diameter of the fruit image.
- Step 5: The grading algorithm is developed using the comparison ratio between the diameter of the fruit image in pixels and the actual fruit diameter in centimeters. The comparison ratio permits grading of different-sized limes according to different provincial criteria.

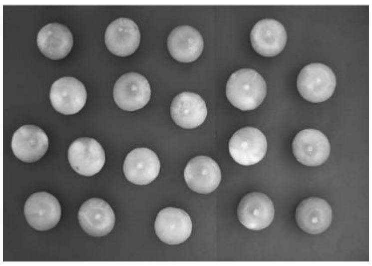

Figure 6. Grayscale image of captured limes

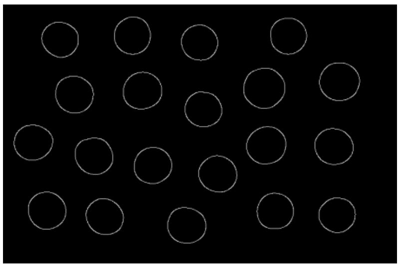

Figure 7. Edge detection using the Canny algorithm

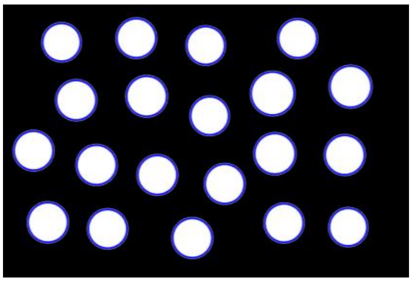

Figure 8. Image segmentation of each fruit

2.2.2. Grading phase
The trained grading algorithm was then used to classify sizes of each lime in an image (Figure 5). It consisted of the same steps as the learning phase (image capture, grayscale conversion, edge detection, image segmentation, and feature extraction), although several fruits were processed concurrently to reduce processing time. For the grading process, the user could define grading parameters such as the number of size classes and diameter threshold values for each lime size (in centimeters). The grading algorithm then classified a lime's size from diameter data according to flexible grading parameters based on each province's size criteria. In the next step, the diameter obtained from the lime fruit image was compared with the thresholds for each lime size defined in the grading parameters. In the final step (graded labeling), a label size was defined for each fruit in an image.

3. RESULTS AND DISCUSSIONS
We first attempted to define the comparison ratio between the diameter of the fruit image in pixels and the actual fruit diameter in centimeters for the grading phase. In this section, we present experimental results using diameter as the main feature for the grading algorithm.

3.1. Comparison of lime size grading using a grading machine and grading algorithm for Phichit Province grading conditions

These experiments used 100 limes of each size. We first demonstrated the performance of mechanical lime grading using size criteria from Phichit Province. Although the process was not very time-consuming, the average grading accuracy was only 92.16% as shown in Table 2. We then derived equivalences for radius (in pixels) for Phichit Province grading conditions as shown in Table 3. Figure 9 shows the radius of all limes in all size classes for this experiment by the grading algorithm. Using these values, we obtained an average accuracy of 99.16% for image-based grading (Table 2). Compared with mechanical grading, our grading algorithm demonstrated greater accuracy for all lime sizes.

Table 2. Performance of grading machine vs. grading algorithm for Phichit Province grading conditions

Lime size	Accuracy using grading machine (%)	Accuracy using grading algorithm (%)
Size 1	98	100
Size 2	85	100
Size 3	90	99
Size 4	87	98
Size 5	93	98
Size 6	100	100
Average	92.16	99.16

Table 3. Equivalences of radius from learning phase for Phichit Province grading conditions

Lime size	Diameter, d (Centimeters)	Radius, r (pixels)
Size 1	$d > 4.5$	$r > 35$
Size 2	$4.2 \leq d \leq 4.5$	$31.7 \leq r \leq 35$
Size 3	$4.0 \leq d < 4.2$	$30.2 \leq r < 31.7$
Size 4	$3.7 \leq d < 4.0$	$27.5 \leq r < 30.2$
Size 5	$3.4 \leq d < 3.7$	$24 \leq r < 27.5$
Size 6	$d < 3.4$	$r < 24$

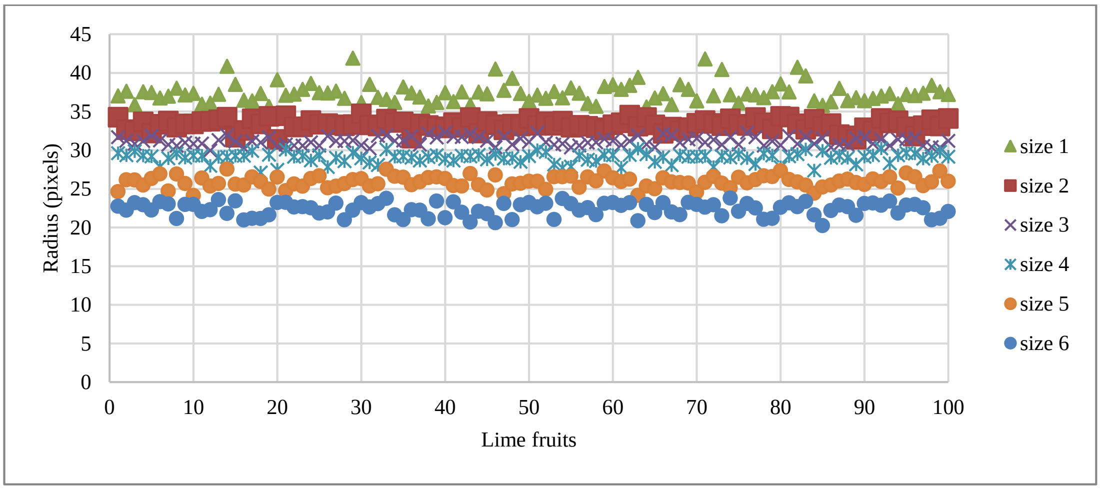

Figure 9. Plot of radius (in pixels) of all limes for Phichit Province grading conditions

3.2. Determination of comparison ratios to define radius ranges of lime size grading using image processing

Table 4 shows the conditions for lime size grading in an experiment using Phichit Province grading conditions. We express the comparison ratios of the image-based diameters of lime fruit (in pixels) to the actual measured diameters (in centimeters) in units of pixels per centimeter (PPC). Based on these results, we used an average comparison ratio of 14.942 PPC, or approximately 15 PPC, which permitted defining each size range according to each province's different size grading criteria.

Table 4. Radius ranges and comparison ratios of each lime size for Phichit Province grading conditions

Lime size	Diameter, d (centimeters)	Radius, r_c (centimeters)	Radius, r (pixels)
Size 1	$d > 4.5$	$r_c > 2.25$	$r > 35$
		comparison ratio = 15.56 PPC	
Size 2	$4.2 \leq d \leq 4.5$	$2.1 \leq r_c \leq 2.25$	$31.7 \leq r \leq 34$
		comparison ratios = 15.09 to 15.56 PPC	
Size 3	$4.0 \leq d < 4.2$	$2.0 \leq r_c \leq 2.1$	$30.2 \leq r < 31.7$
		comparison ratios = 15.1 to 15.09 PPC	
Size 4	$3.7 \leq d < 4.0$	$1.85 \leq r_c \leq 2.0$	$27.5 \leq r < 30.2$
		comparison ratios= 14.86 to 15.1 PPC	
Size 5	$3.4 \leq d < 3.7$	$1.7 \leq r_c \leq 1.85$	$24 \leq r < 27.5$
		comparison ratios = 14.11 to 14.86 PPC	
Size 6	$d < 3.4$	$r_c < 1.7$	$r < 24$
		comparison ratios = 14.11 PPC	
	Average of comparison ratios 14.942 ≈ 15 PPC		

The experiment used an initial average comparison ratio of 15 PPC to define the conditions for grading limes from Phichit Province as shown in Table 5. The results showed an accuracy of 96.33%, which was better than that obtained by mechanical grading. However, the largest errors occurred in size 2 because of the similarity of some fruits to those of size 1. Therefore, we changed to defining radius ranges using the maximum comparison ratio of 15.56 PPC (based on $d \geq 4.5$ cm), and reanalyzed the data, improving the average accuracy to 99.83% as shown in Table 6.

Table 5. Radius ranges using average comparison ratio of 15 pixels per centimeter for Phichit Province grading conditions

Lime size	Diameter, d (centimeters)	Radius, r (pixels)	Accuracy using grading algorithm (%)	Accuracy using grading machine (%)
Size 1	$d > 4.5$	$r > 33.75$	100	98
Size 2	$4.2 \leq d \leq 4.5$	$31.73 \leq r \leq 33.75$	80	85
Size 3	$4.0 \leq d < 4.2$	$30.22 \leq r < 31.73$	99	90
Size 4	$3.7 \leq d < 4.0$	$27.95 \leq r < 30.22$	99	87
Size 5	$3.4 \leq d < 3.7$	$25.67 \leq r < 27.95$	100	93
Size 6	$d < 3.4$	$r < 25.67$	100	100
	Average accuracy		96.33	92.16

Table 6. Radius ranges using maximum comparison ratio of 15.56 pixels per centimeter for Phichit Province grading conditions

Lime size	Diameter, d (centimeters)	Radius, r (pixels)	Accuracy using grading algorithm (%)	Accuracy using grading machine (%)
Size 1	$d > 4.5$	$r > 35.01$	100	98
Size 2	$4.2 \leq d \leq 4.5$	$32.67 \leq r \leq 35.01$	100	85
Size 3	$4.0 \leq d < 4.2$	$31.12 \leq r < 32.67$	99	90
Size 4	$3.7 \leq d < 4.0$	$28.77 \leq r < 31.12$	100	87
Size 5	$3.4 \leq d < 3.7$	$26.45 \leq r < 28.77$	100	93
Size 6	$d < 3.4$	$r < 26.45$	100	100
	Average accuracy		99.83	92.16

Based on these findings, we next applied these grading conditions (using the maximum comparison ratio of 15.56 PPC) to grading by other provinces' size criteria. The accuracies of grading according to the criteria of Phetchaburi, Kamphaengphet, and Tak Provinces are shown in Tables 7-9, respectively. The average size grading accuracy for all provincial conditions was 99.59, which exceeded that of mechanical grading as shown in Table 10. The average processing time was 1.70 seconds per fruit as shown in Table 11.

Table 7. Radius ranges using maximum comparison ratio of 15.56 pixels per centimeter for Phetchaburi Province grading conditions

Lime size	Diameter, d (centimeters)	Radius, r (pixels)	Accuracy using grading algorithm (%)	Accuracy using grading machine (%)
Size 1	$d > 4.5$	$r > 35.01$	100	98
Size 2	$4.3 \leq d \leq 4.5$	$33.45 \leq r \leq 35.01$	100	87
Size 3	$3.5 \leq d < 4.3$	$27.23 \leq r < 33.45$	98	91
	Average accuracy		99.33	92.00

Table 8. Radius ranges using maximum comparison ratio of 15.56 pixels per centimeter for Kamphaengphet Province grading conditions

Lime size	Diameter, d (centimeters)	Radius, r (pixels)	Accuracy using grading algorithm (%)	Accuracy using grading machine (%)
Size 1	$d > 5.2$	$r > 40.45$	100	100
Size 2	$5.0 \leq d \leq 5.2$	$38.9 \leq r \leq 40.45$	100	99
Size 3	$4.8 \leq d < 5.0$	$37.34 \leq r < 38.9$	100	98
Size 4	$4.6 \leq d < 4.8$	$35.78 \leq r < 37.34$	100	98
Size 5	$4.4 \leq d < 4.6$	$34.23 \leq r < 35.78$	99	91
Size 6	$4.1 \leq d < 4.4$	$31.89 \leq r < 34.23$	98	88
Size 7	$3.8 \leq d < 4.1$	$29.56 \leq r < 31.89$	99	90
Size 8	$d < 3.8$	$r < 29.56$	100	100
	Average accuracy		99.5	95.50

Table 9. Radius range using average comparison ratio of 15.56 pixels per centimeter for Tak Province grading conditions

Lime size	Diameter, d (centimeters)	Radius, r (pixels)	Accuracy using grading algorithm (%)	Accuracy using grading machine (%)
Size 1	$d > 5.2$	$r > 40.45$	100	100
Size 2	$5.0 \leq d < 5.2$	$38.9 \leq r \leq 40.45$	100	99
Size 3	$4.8 \leq d < 5.0$	$37.34 \leq r < 38.9$	100	98
Size 4	$4.4 \leq d < 4.8$	$34.23 \leq r < 37.34$	100	93
Size 5	$4.2 \leq d < 4.4$	$32.67 \leq r < 34.23$	100	89
Size 6	$3.8 \leq d < 4.2$	$29.56 \leq r < 32.67$	98	92
Size 7	$d < 3.8$	$r < 29.56$	100	100
	Average of accuracy		99.71	95.86

Table 10. Grading accuracy for all provincial conditions

Provinces	Accuracy using grading algorithm (%)	Accuracy using grading machine (%)
Phichit	99.83	92.16
Phetchaburi	99.33	92.00
Kamphaengphet	99.50	95.50
Tak	99.71	95.86
Average	**99.59**	**93.88**

Table 11. Processing time of all provincial conditions

Provinces	Processing time (seconds)
Phichit	1.56
Phetchaburi	1.40
Kamphaengphet	1.96
Tak	1.88
Average	**1.70**

4. CONCLUSION

Our results suggest that radius (or diameter) is a dominant feature that enables grading of lime fruit sizes by image analysis. The accuracy of image-based lime size grading was found to be higher than mechanical grading for all provincial size criteria. In addition, we demonstrated that our grading algorithm is sufficiently flexible for grading with different regional lime size criteria, using the maximum comparison ratio of the radius in pixels to the measured radius size of the actual lime fruit. The grading accuracy of lime sizes for four provincial conditions was 99.59%, and the average processing time per fruit was 1.70 seconds. Hence, we believe that this method can be applied not only to size grading of limes from regions with different size criteria, but to different agricultural products as well.

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