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Non-destructive mango quality assessment using image processing: inexpensive innovation for the fruit handling industry

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Introduction

Thailand is one of the most important mango (*Mangifera indica L.*) producers and exporters in Southeast Asia. Current fruit sorting techniques in Thailand are done by hand, which is tedious and inaccurate. Therefore, there is a need to improve the efficiency and accuracy of fruit quality assessment which can meet the demands of high-value markets. Low-cost and non-destructive sensing technologies capable of sorting fruits according to their properties have a potential to fulfill the need. Computer vision system (CVS) and image processing have been applied increasingly for sorting applications in recent years. Computer vision is a technology which produces precise and meaningful descriptions of physical objects from images (BALLARD AND BROWN, 1982). Image processing is a non-destructive method which processes signals of an image and the output can be either an image or, a set of characteristics or parameters of interest related to the image. Color of mango fruits is a decisive factor for consumers' acceptance. External defects such as anthracnose, bruises and latex stains often go undetected in hand sorting due to their delayed development until several days after initiation. Advanced methods to precisely determine these quality parameters would be useful in assuring nutritional and economic value of fruits. Studies on the application of image processing for quality inspection of Thai mangos will make a significant contribution to the implementation of new sorting technologies. This will allow fruit producing and packaging companies to increase the value of their products, enabling them to offer to their customers a "premium class".

Material and Methods

A CVS was built for the purpose of this study. Several models of webcams as well as a standard digital camera were used to capture images of the mango fruits. Standard illumination (D65, 6500 K) was installed in the chamber of the system. A conveyor belt was used to feed the fruits through the system and photos were automatically captured and labeled for later comparison with corresponding reference analysis. A simple CVS for capturing images under UV-A illumination was built separately for the defects detection. The structure of the system was made of a white foam box with UV-A illuminants fixed to the ceiling. The camera and webcams captured images through a hole on the ceiling of the foam box. While capturing images the lid of the box was closed to create a darkened environment.

Two important export varieties of Thai mango, namely '*Nam Dokmai*' and '*Maha Chanok*' were used for experiments. Fruits were allowed to ripen for up to 8 days. Color was evaluated using the CVS by obtaining RGB values. Reference color data was acquired based on the CIE L*a*b* color space, which is the most commonly used system in the measuring of color in food due to the uniform distribution of colors, and because it is very close to human perception of color (LEÓN *ET AL.*, 2006). Ten fruits were randomly selected per sampling date. Point measurements were taken using a colorimeter (MiniScan XE PLUS, Hunter, Inc., U.S.A.) at six positions per fruit; from the upper and lower halves (head end, middle and tip end, respectively) of both sides of the fruit.

Fruits from each lot were inoculated with the anthracnose disease using the method published by CORKIDI *ET AL.* (2006). Suspensions (5 mL) of *C. gloeosporioides* were applied to 10 fruits with an aerosol spray bottle. Ten fruits were left untreated as a control. Bruising was simulated by applying varying degrees of force using a TA.XT Plus Texture Analyzer (Stable Micro Systems, Ltd., U.S.A.) equipped with a spherical probe. Latex staining was simulated by inducing latex exudation from freshly harvested fruits and allowing the seeping of latex onto the skin of mango fruits in a controlled fashion. The latex stains were induced to three positions per fruit; from the upper and lower halves (head end, middle and tip end, respectively) on one side of the fruit.

The image data in RGB color space acquired by using webcams was transformed into L*a*b* color space by using the conversion models published by KANG *ET AL.* (2008). Image data (JPEG format) was analyzed using ImageJ software (National Institutes of Health, U.S.A.) to obtain the RGB values. Then, the RGB image data was transformed into L*a*b* color space by using the established conversion method. Image data was analyzed using SAS (SAS Institute Inc., U.S.A.) to evaluate the correlation between the image parameters (L*, a* and b*) from RGB digital images and colorimeter. For the defects detection, the images acquired by the computer vision system were segmented using different techniques. The best segmentation technique for each defect was identified. The lighting effect of the standard and UV-light was compared to determine optimal conditions for detection of each defect.

Results and Discussion

Table 1 shows the mean L*a*b* values as measured by colorimeter and estimated by CVS. Regression analysis for '*Nam Dokmai*' showed that there was a statistically significant association ($p<0.0001$) of measured and estimated L*a*b* values and the Pearson correlation coefficient was always greater than 0.85, except for the correlation coefficient for the L* values of the '*Nam Dokmai*' ($r=0.69$). For '*Maha Chanok*' fruits, the CVS showed significant correlations ($r>0.81$) to values obtained from the colorimeter. The results of color measurement indicated that the CVS was capable of collecting accurate color data from both Thai mango varieties. KANG *ET AL.* (2008) found that this calibration can be used for bicolor fruit, namely the 'B74' mango. In their study, the effect of curvature was corrected. In this study, the calibration model was tested for the color measurement of Thai mango varieties. The variety '*Nam Dokmai*' has a homogenous golden yellow peel color after ripening. On the other hand, the '*Maha Chanok*' is a bicolor fruit, having a yellow-green peel with a red shoulder. The study showed that the CVS color estimation of the '*Maha Chanok*' was more accurate than the '*Nam Dokmai*'. Therefore the calibration model is more suitable for bicolor fruits.

Table 1: Mean L*a*b* values from the two mango varieties as measured by colorimeter and estimated by CVS

	*L**		*a**		*b**	
	Measured	*Estimated*	*Measured*	*Estimated*	*Measured*	*Estimated*
Nam Dokmai	72.38	63.62	2.90	-4.18	35.74	40.98
Maha Chanok	69.26	76.38	7.94	-12.97	42.47	66.55

The study has found that the digital camera performed better in collecting image data required for the detection of the anthracnose disease. In addition, the detection of anthracnose infection at the early stage of disease development was possible only under UV-A illumination (Figure 1). The application of UV-A illuminant in hand sorting of mango can improve the accuracy and efficiency of the anthracnose detection.

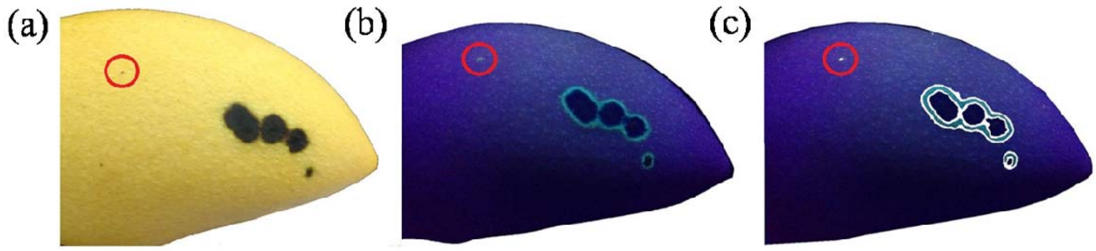

Figure 1: Images of anthracnose lesions taken by using a CMOS camera: (a) small anthracnose lesion (in the red circle) easily overlooked when viewed under standard illumination, (b) small anthracnose lesion fluoresced under UV-A illumination and (c) segmented image of mango in part showing anthracnose lesions extraction.

The study showed that the digital camera (Sony Cyber-shot DSC-HX5) performed better in collecting image data required for the detection of the bruises. The change in color intensity was the only feature of bruising, which was possible to extract from the images. After image segmentation, the bruised area was detected and evaluated. Unfortunately, the application of UV-A illumination did not improve the ability of the detection. Only severe bruises on mango fruits were able to be detected by processing images taken by the commercial camera (Figure 2). The study has found that the low-cost webcam (Logitech c270h) was sufficient for collecting image data required for the detection and evaluation of the latex stains, as they were easily detected and evaluated under UV-A illumination (Figure 3).

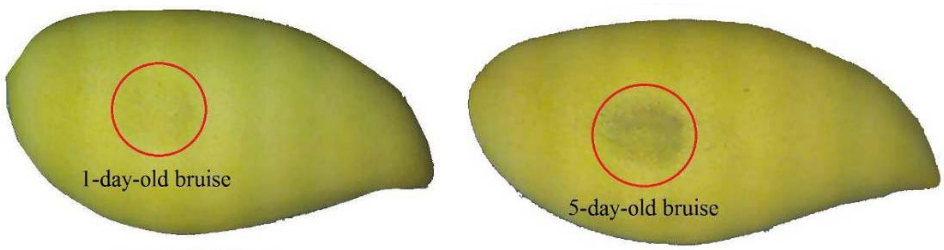

Figure 2: Digital images of slight (1-day-old) and severe (5-day-old) bruises on mangos

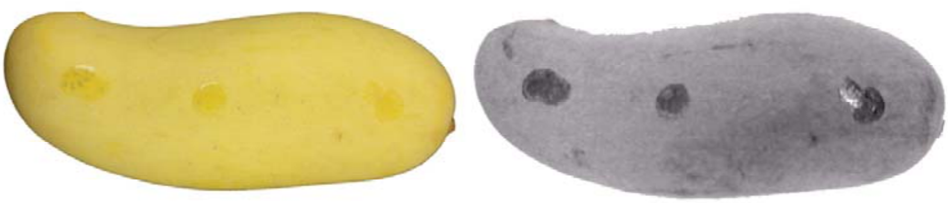

Figure 3: Latex stains on mango fruits under standard (left) and UV illumination (right)

Conclusions and Outlook

There was a good prediction of CIE L*a*b* values by using RGB values from the CVS. Anthracnose severity can be evaluated under standard illumination using digital camera and image segmentation. Anthracnose infection can be detected at earlier stage of disease development by measuring under UV-light. Only severe bruising can be identified and evaluated quantitatively under standard illumination by image processing. Latex stains can be easily detected and evaluated under UV-light using a low-cost webcam. The CVS and image processing have been proved to be low-cost technologies, which can be applied for color and external defects assessment of mango fruits. Efficiency and accuracy of the sorting and grading by hand can be improved by integrating some low-cost sensing technologies. For instance, the use of UV-A illumination can facilitate the early detection of anthracnose in hand sorting.

Based on the findings of this study, it is strongly recommended that better performance cameras and webcams are required for the defects detection. Furthermore, higher intensity UV illuminants and suitable wavelength need to be investigated. In order to detect anthracnose infection at the earliest stage of disease development, complete microbiological and photochemical analyses are required. The developed computer vision system shows encouraging potential for the application in automatic sorting and grading of mango fruits for the export industry in Thailand. However, the CVS which was built for the purpose of this study cannot inspect the entire fruit surface. Therefore an additional feature capable of capturing images of the entire fruit has to be developed in the next phase of the project.

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