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Application of Computer Vision in the Detection of Chilling Injury in Bananas

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ABSTRACT

Bananas were chilled at 6°C and the appearance of brown spots when exposed to ambient air, a phenomenon known as chilling injury (CI), was detected using computer vision. The system consisted of a digital colour camera for acquiring images, an illumination set-up for uniform lighting, a computer for receiving, storing and displaying of images and software for analyzing the images. The RGB colour space values of the images were transformed into that of HSI colour space which is intuitive to human vision. Visual assessment of CI by means of a browning scale was used as a reference and correlation between this reference values and hue was investigated. Results of the computer vision study successfully demonstrate the potential of the system in substituting visual assessment in the evaluation of CI in bananas. The results indicate significant influence, at $\alpha=0.05$, of treatment days and temperature on hue. A strong correlation was also found between hue and visual assessment with $R>0.85$.

Keywords: Computer vision, imaging, chilling injury, banana, hue

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INTRODUCTION

The computer vision system (CVS) has been used increasingly for inspection and grading of agricultural produce in recent years. Articles regarding the feasibilities of the system and their reviews have been published by researchers since a decade ago (Tillet, 1991; Gunasekaran, 1996; Chen *et al.*, 2002; Brosnan & Sun, 2004; Du & Sun, 2004). The

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effectiveness of the system has been shown on many kinds of fresh produce and food such as cherries (Beyer *et al*., 2002), tomatoes (Lana *et al*. 2006), mangoes (Kang *et al*., 2008), bananas (Roberto *et al*. 2009), pizzas (Du & Sun, 2005) and salmon fillets (Quevedo *et al*., 2010).

A digital colour camera in the CVS system generates RGB (red-green-blue) images that are device dependent (Yam & Papadakis, 2004; Mendoza *et al*., 2006; Cubero *et al*., 2011). To overcome this problem, the colours are transformed to other colour space such as the HSI (hue-saturation-intensity) and the L*a*b*. Hue is a commonly used colour coordinate in image processing because it is more intuitive to human vision (Cheng *et al*., 2001; Du & Sun, 2005). Generally, hue is considered as the angle between the reference line and the colour point in RGB space. The hue value varies from 0° to 360°, reflecting colours ranging from blue, yellow, green to magenta (Cheng *et al*., 2001). The method of using hue coordinates for colour evaluation is highly effective with more than 90% accuracy achieved in the inspection of potatoes and apples (Tao *et al*., 1995) and bell peppers (Shearer & Payne, 1990). Meanwhile, an accuracy of 96.7% was achieved in pizza classification (Du & Sun, 2005) and average error of approximately 2° in colour measurement was obtained in different curvatures of mangoes (Kang *et al*., 2008).

The application of computer vision in the detection of chilling injury (CI) in bananas is, however, still limited. CI is one of the physiological disorders that can appear if an agricultural produce is stored at low temperatures and the banana is one of the chilling sensitive produce that may show CI symptoms when exposed to a temperature below 10°C (Murata, 1969; Abd El-Wahab & Nawwar, 1977; Broughton & Wu, 1979; Nguyen *et al*., 2003). The symptoms may appear most severe at 6°C (Nguyen *et al*., 2003) but can tolerate well to a temperature range of 13-14°C (Zhang *et al*., 2010).

The most common visual symptom of CI is colour change. The quantification and characterization processes which are usually made by visual inspection may lead to considerable variation in results due to the differences in human evaluation, perception and human error. This has encouraged scientists to look for various ways of quantifying colour changes involving computer-based techniques.

Hence, the application of computer vision to replace the conventional method is investigated and subsequently suggested. The objectives of this paper are: i) to investigate colour changes due to CI in bananas using computer vision; and ii) to compare the performance of hue against visual assessment as a CI indicator.

MATERIALS AND METHODS

Materials

A batch of good quality hands of ripe bananas (*Musa Cavendish*) were obtained from a local market in Potsdam, Germany. The bananas were then transported to the laboratory at Leibniz Institute of Agricultural Engineering Potsdam-Bornim, Germany. Sixteen fingers of bananas were selected for the experiment. Images of the bananas were taken and visual assessment was also immediately carried out before storage (i.e. beginning of day 1). Then, eight bananas were allowed to ripen in a control temperature at 13°C, while another eight were stored at 6°C (rH 90-95%) for 2 days to induce CI. At the end of day 2 (i.e. beginning of day 3), the bananas were taken out and their images were taken and visual assessment carried out immediately upon exposure to ambient temperature (15-20°C). This was repeated after one day of exposure to ambient temperature (i.e. beginning of day 4).

Visual Assessment

Visual assessment was conducted immediately after image acquisition. The assessment was based on browning scale as described by Nguyen *et al*. (2003). The browning scale was rated as follows: 1 = no chilling injury symptoms appear; 2 = mild chilling injury symptoms in which the injury can be found in between the epidermal tissues; 3 = moderate chilling injury symptoms in which the brown patches begin to become visible, larger and darker; 4 = severe chilling injury symptoms in which the brown patches are visible, larger and darker than at scale 3; 5 = very severe chilling injury symptoms in which the patches are relatively large on the surface.

Computer Vision System

A computer vision system developed by the Institute of Agricultural Engineering, Potsdam, Germany with CCD camera JVC KY-F50E (zoom lens F2.5 and focal lengths of 18-108 mm) was used to capture the images of bananas. The size of the captured image was 720x576 pixels by 24 bits. The bananas were illuminated using four fluorescent lamps arranged as front lighting at a height of 35cm above the samples in the form of a square for uniform effect. The angle between the camera lens axis and the lamps was 45° since diffused reflections responsible for colour occurred at 45° from the incident light. Optimas grabber board (Bioscan Inc., USA) software was used to acquire the images directly on the computer display and store them in the computer in bmp format.

All the acquired images were processed and analysed using Matlab software. The overall process is as presented in Fig.1.

A segmentation process was applied to separate the part of interest (the true image of a banana) from the background. This process is critical in image processing and it is done to eliminate the influence of the background pixel information on the RGB value of the banana. The threshold value used was obtained from a histogram of the gray-scale image (Fig.2), which is the conversion image of the original image of the banana. Morphological dilation was performed to remove background noise, and this was followed by a mask operation to get back the original colour of the segmented image resulting in a binary image and finally the true image of the bananas (Fig.3). The RGB values were then extracted from the image and converted to hue value using the following transformation:

$$H = \begin{cases} 2\pi - \cos^{-1}\left\{\dfrac{[(R-G)+(R-B)]}{2\sqrt{(R-G)^2+(R-B)(G-B)}}\right\}, & B > G \\ \cos^{-1}\left\{\dfrac{[(R-G)+(R-B)]}{2\sqrt{(R-G)^2+(R-B)(G-B)}}\right\}, & otherwise \end{cases}$$

[Equation 1]

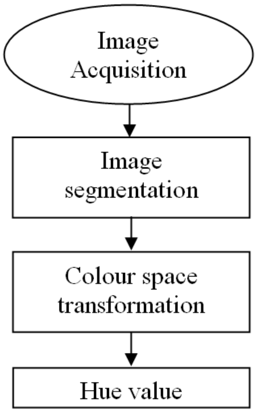

Fig.1: A schematic representation of the colour transformation process

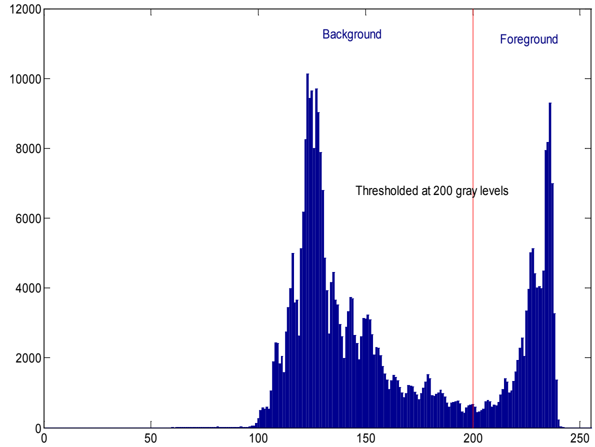

Fig.2: Histogram of gray-scale image

Statistical Analysis

Statistical analysis was performed using the SAS statistical software. Meanwhile, the analysis of variance (ANOVA) was used to compare the mean values of the sample hues at different treatment factors (treatment days and temperature). Then, the mean comparison test using Least Significant Difference (LSD) was conducted to compare the treatment group means after the ANOVA results had been shown to be significant. Finally, a correlation analysis between the hue and visual assessment values was conducted to find the relationship between them.

RESULTS AND DISCUSSION

Colour Change

The colour of bananas stored at 6°C changed from bright yellow at the beginning of the experiment to brown after being exposed to ambient temperature. The change in the colour was parallel to the change in the hue values (Fig.4).

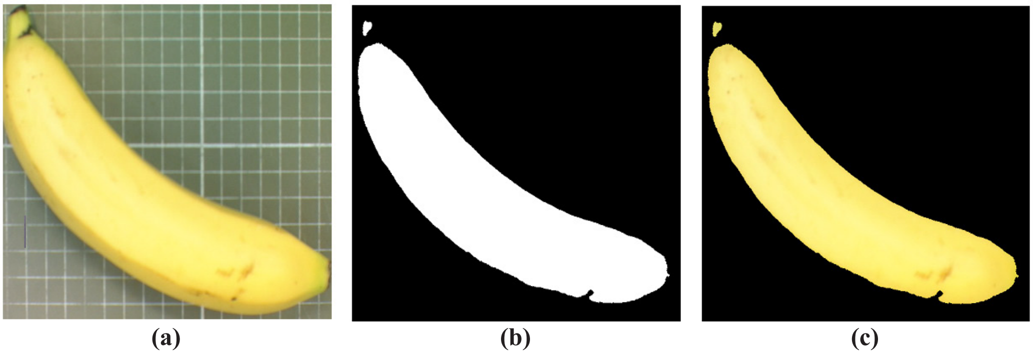

Fig.3: Banana images: (a) an original image, (b) a binary image and (c) a true image of the banana

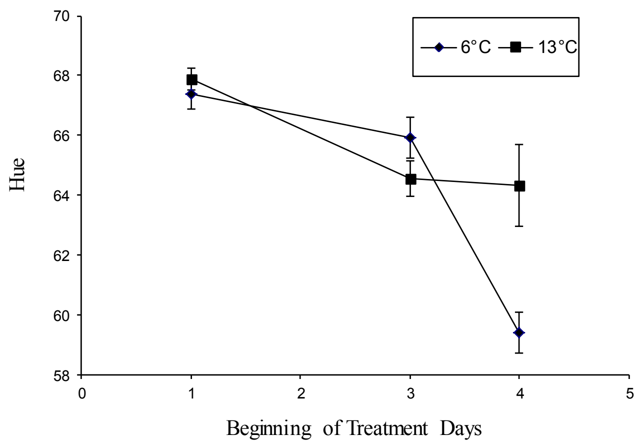

Fig.4: Change of hue values by treatment days

The change became severe when the exposure was prolonged. This is illustrated by the steep slope of the plot between the beginning of day 3 and day 4. At the beginning of day 4, i.e. after one day of exposure to ambient temperature, the hue value dropped to below 60°, which corresponded to brown in the HSI colour chart. Meanwhile, no change was observed on the control samples. The slight decrease that was shown in the hue value on the control samples was basically due to the normal ripening process.

The results of ANOVA revealed that the individual main effects, i.e., treatment days and temperature were statistically significant at $\alpha = 0.05$ (Table 1). In agreement with Skog (1998), the results also showed that there was a significant interaction ($p<0.05$) between the treatment days and the level of temperatures. In other words, the treatment days, the level of temperature and the interaction between them significantly affected the hue values and are thus important factors contributing towards the severity of CI in bananas. The lower the temperature is below the threshold temperature, the sooner and the more severe will be the resulting injury. The longer the duration of exposure to lower temperature, the more severe will be the CI.

Further analysis using the LSD test indicates that the day(s) of treatment was statistically different from each other (Table 2). Similar response was observed in the temperature analysis.

Post-hoc analysis showed that both the levels of temperature were statistically different (Table 3). This means that each level of temperature gives different effects to the CI symptoms. Bananas stored at 6°C were severely affected by CI, while bananas stored at 13°C were not affected and ripened normally.

TABLE 1: ANOVA of CI factors

Source	DF	Mean Square	F Value	Pr > F
Treatment Days	2	134.5183099	138.71	<.0001
Temperature	1	21.9351723	22.62	<.0001
Treatment days*temperature	2	41.7632839	43.06	<.0001

TABLE 2: Comparison of means of treatment days

t Grouping	Mean	Treatment days
A	67.6403	1
B	65.2408	3
C	61.8685	4

TABLE 3: Comparison of means of level of temperature

t Grouping	Mean	Temperature
A	65.5925	13
B	64.2405	6

Correlation

Correlation studies indicated the existence of a relationship between hue values and visual assessment, with R = 0.852. The correlation result is significant at $\alpha = 0.05$. Thus computer vision could be a feasible substitute for visual assessment in the evaluation of CI in bananas. At the end of the experiment, the brown patches became larger and darker, indicating an increasingly severe CI on the bananas. Parallel to the colour changes, the value of hue increased until a maximum value of 68.23 was reached. Descriptive statistics for hue and visual assessment is illustrated in Table 4. Meanwhile, the variation in hue with visual assessment is illustrated in Fig.5.

TABLE 4: Descriptive statistics of visual assessment and hue

Variable	Mean	Standard Deviation	Sum	Minimum	Maximum
Visual assessment	2.4792	1.1839	59.5000	1.0000	4.0000
Hue	64.2405	3.6494	1542	58.4071	68.2317

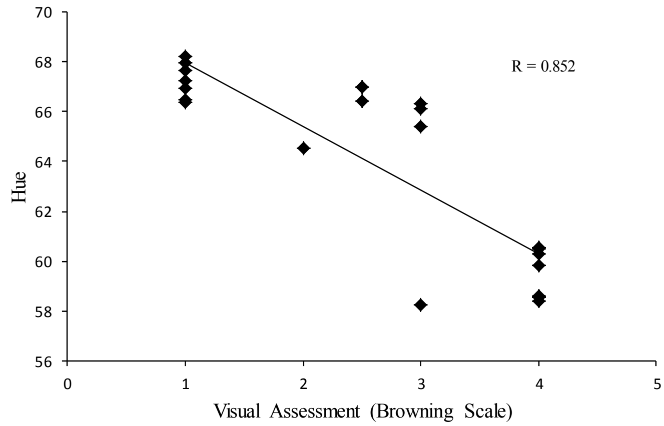

Fig.5: The correlation between hue values and visual assessment

CONCLUSION

The results of this study have successfully demonstrated the potential of applying computer vision in the detection of CI in bananas. In particular, treatment days and temperature level are important factors affecting the severity of the CI symptoms. The correlation between hue and visual assessment values indicates a high potential for the system to replace the conventional method and to offer objectivity in and automation possibility to the sorting process.

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