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THE INFRARED THERMAL IMAGE-BASED MONITORING PROCESS OF PEACH DECAY UNDER UNCONTROLLED TEMPERATURE CONDITIONS

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ABSTRACT

In this paper, we developed a monitoring method for identifying decayed fruit tissues and the degree of decay under the conditions of uncontrolled temperature and naturalconvection. The monitoring results showed that temperature differences between the decayed tissues and sound tissues were significant and varied with decayaggravation. The maximum temperature difference was 0.7 °C. After deducting the influence of the environmentaltemperature, we extracted and analyzed the infrared thermal images of the decayed tissues. The results indicated that the temperaturedifference between decayed and sound tissues can be used to identify the location and degree of decayed tissue. The paper provides the monitoring method of fruit surface decay and the extraction and calculation method of the decay area and degree.

Keywords: decay; uncontrolled temperature; infrared thermal imaging; image processing.

INTRODUCTION

Fruit decays easily during storage and shelf life as a result of bruises caused by mechanical force during harvest and physiological defects developed in the growth period (Bowen and Watkins 1997; Harker *et al*. 1999). Traditional discrimination methods are based on subjective human sensory information. In recent years, a method to detect the fruit bruises and physical defects based on optical technology was reported. For example, X-ray imaging (Diener *et al*. 1970; Kim and Schatzki 2000; Schatzki *et al*. 1996; Thomas *et al*. 1995) and magnetic resonance imaging (Chen *et al*. 1989; Clark *et al*. 1998; Wang *et al*. 1988) can detect fruits bruises effectively. However, the relatively high equipment cost makes these techniques less practical for fruit bruise detection. Reflectance (Brown *et al*. 1974; Pen *et al*. 1985; Upchurch *et al*. 1994) and reflectance imaging (Wen and Tao 2000) are two potential low-costbruise detection techniques; however, both are affected by thefruit's skin color variation, so illumination equipment is required to illuminate the fruit surface during the detection process.

Infrared thermal imaging (Danno *et al*. 1978) is a non-destructive and non-contact infrared sensing technique for measuring the radiation energy emitted from object surfaces. Compared with X-ray imaging and magnetic resonance imaging techniques, infrared thermal imaging has a low cost and can be used flexibly and quickly. Therefore, this technique has been widely used as a diagnostic monitoring tool in agriculture and biology (Fito *et al*. 2004; Gowen *et al*. 2010; Jone 1999; Vadivambal and Jayas 2011; Walczak *et al*. 2003). Temperaturedifferences between bruised tissues and sound tissues caused by their different thermal diffusion coefficients can be detected through infrared thermal imaging (Danno *et al*. 1978; Varith *et al*. 2003). After artificially bruised apples were maintained under the conditions of 26 °C and 50% RH for 48 hours, bruises on the apples surfaces were detected successfully with infrared thermal imaging in the forced convection environment (Varith *et al*. 2003). Infrared thermal imaging techniques evaluated the quality of apples before the storage and shelf period when the storage temperature gradually declined (Veraverbeke *et al*. 2006). The difference (18.5 °C) between low ambient temperatures and apple surface temperature was enough to discriminate the watercore apples (Baranowski *et al*. 2008). With the development of optical technology, early apple bruiseshave been detected with pulsed-phase thermography (Baranowski *et al*. 2009). Previously developed optical methods for detecting fruit bruises or defects were almost all carried out incontrolled temperatures and forced convection. This does not match real-life uncontrolled temperature environments during the fruit storage and shelf life. Although bruised apples were detected under the changing temperature and natural convection conditions (Diener *et al*. 1970), they did not study the monitoring method of fruit decay in a realistic environment. At the same time, the response of the thermal imaging system based on the uncooled microbolometer was closely related to background temperature. Therefore, the temperature measurement accuracy was low. This increases the difficulty of monitoring the fruit decay process when temperature is uncontrolled.

The paper aims to study a method for monitoring peach decay process based on infrared thermal imaging under the condition of uncontrolled temperature. The experiment simulated the environment during the fruit storage and shelf life. The results obtained could help establish a method to monitor fruit decay. The study included two aspects. First, we determined if there was a temperature difference between the decayed tissues and sound tissues or if the temperature difference varied with the aggravation of the peach decay degree. Second, we determined if the temperaturedifference between the decayed tissues and sound tissues could indicate the decayed range and degree of peach tissues.

MATERIALS AND METHODS

Seven fresh Ping Gupeaches were obtained from the fruit market in Pinggu, Beijing and bruised artificially. Then the bruised three, two and two peaches were placed on the top, middle, and bottom layers of the shelf.

Infrared thermal images of the peach surface were taken with the FLIR SC620 (FLIR Systems, INC., US, Portland) system with a spectral response range from 7.5 μm to 13 μm and a temperature sensitivity of 0.04°C at 30°C. In the FLIR SC620 system, the 640×480-pixel uncooled micro bolometer focal plane arraycan produce sharp images with high accuracy radiometric temperature readings. The temperature measurement range of this system is from -40°C to 500°C, and the accuracy is ±2°C or ±2% of readings. Additionally, we used a CCD camera to acquire the images of the peaches. The two cameras were fixed on two tripods 0.4 m away from the peach surfaces. The emissivity of the peach fruit was set to 0.96(Veraverbeke *et al*., 2006).Fig. 1 shows the schematic diagram of the monitoring system of the peach decay process under the condition of uncontrolled temperature. FLIR Research IR software developed for infrared thermal image analysis by FLIR Systems Inc. was used to analyze the peach surface temperature and convert the thermalimage into an appropriate format for image processing. Image processing and numerical calculation were performed with Matlab 7.0.

Infrared thermal and visible images and measurement time were acquired twice eachday.All peaches were not guaranteed to decay in uncontrolled temperatures, so a peach with a suitable decay level was selected for analysis. Absolute temperature differences between the decayed tissues and sound tissues were analyzed with FLIR Research IR. Image processing software and data calculation was performed with Matlab 7.0. The area including the decayed tissues and sound tissues were taken from the infrared thermal image. The gray value in the same areaaccumulated, and then the ratio of decay area to edge was extracted and calculated respectively.

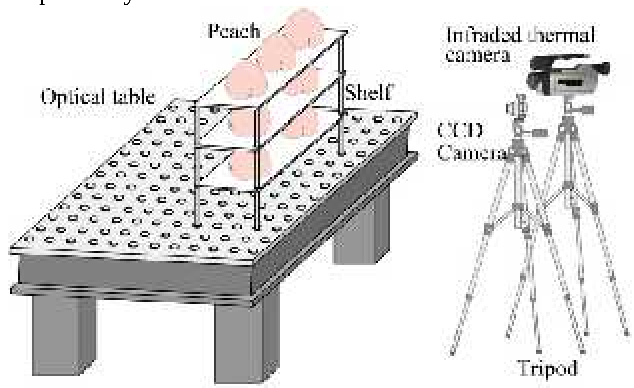

Fig. 1 Schematic diagram of monitoring system for decayed process of peach under the condition of uncontrolledtemperature.

RESULTS AND DISCUSSION

Visible images of the decay process are shown in Fig. 2. These peaches were masked with number, as shown in Fig. 2(f). Since ambient light intensity varied over time, the brightness of these visible images was also different. After observing the visible images of seven peaches, the seventh peach that had suitably decayed was selected as the analysis object. The surface color differences between the decayed tissue and sound tissue gradually became significant (Fig. 2(d)-Fig.2(e)). From Fig. 2(e) to Fig. 2(f), decayed tissues mildewed seriously and were covered with a thin layer of mold. Although the tissue decay degree gradually increased (Fig. 2(a)-Fig. 2(d)), the visible images showed no change. Therefore, the monitoring method based on the machine vision technique was not effective when the fruits decayed slightly.

Infrared thermal images corresponding to the visible images in Fig. 2 are shown in Fig. 3. The reason for the significant background difference of these infrared thermal images was that ambient temperature varied with time. When a black body was not available within the camera's field of view for real-time calibration, infrared thermal imaging based on temperature differences had low precision for absolute temperature measurement.

As shown in Fig. 3, in order to analyze temperature differences between the decayed tissues and sound tissues, FLIR Research IR marked six lines (Li1 to Li6) that passed through the decayed tissues and sound tissues, and each line contained 125 pixels.

As shown in Fig. 4 (a), the absolutetemperature of the decayed tissues and sound tissues did not vary with the aggravation of the decay degree because of the variation of environment temperature and measuring error of the FILR system. Therefore, it was not feasible to determine decay with the index of the peach's absolute temperature. However, in the temperature curves in Fig. 4 (a), the decayed tissues and sound tissues show the temperature difference. Fig. 4(b) shows the difference of average temperature between decayed and sound tissues. This difference was small at the beginning of the decay process, but it gradually increased with the aggravation of decayed degree, until it reached 0.7 °C after 32 hour. However, the temperature differences at 46 hour and 53 hour were lower than that at 32 hour, due to the severe mildew.

Although the visible images of decayed tissues showed no significant change in the early decay stage, the temperature difference between the decayed tissues and sound tissues varied over time. On the basis of these conclusions, we further studied the extraction and calculation method of the edge and area of the decayed peach tissues. Firstly, we selected a pixel of sound tissue as a reference point. Then, with digital image processing technology, pseudo-color images including the decayed tissue were intercepted from the infrared thermal images, after subtracting the grey value of thereference point. These pseudo-color images consist of 124×124 pixels, and the edges of decayed tissues were extracted from these pseudo-color images. Fig. 5 shows the pseudo-color images and edges of decayed tissues. These pseudo-colors represent the decayed degree. Light colors indicate slight decay, and dark colors indicate serious decay. At 1 hour after placing the peaches on the shelf, light pseudo-colors and a small area of decayed tissues indicated that the peach was sound or slightly bruised. This could be confirmed by small temperature difference after 1 hour in Fig. 4 (b). In Fig. 5, from 7 h to 46 hour, dark pseudo-colors and the large area of decayed tissues indicated that the decay degree gradually increased over time. Although the pseudo color of the decayed tissues at 53 hour was darker than that at 46 hour, the area of decayed tissues did not increase significantly. The reason for this phenomenon might be that the surface physical properties of the decayed tissues varied with mildewing.

In order to intuitively observe the area variation of decayed tissues, the ratio of decayed tissue area to the peach area at different times was calculated. Fig. 6 shows the calculation results. Fig. 6 (a) shows edges of the decayed tissue from 1 hour to 53 hour. Obviously, part of edges between 46 hour and 53 hour were overlapped. The curve of area ratio in Fig. 6 (b) indicates that the area of decayed tissues varied slightly. Therefore, it was not feasible to evaluate the decay degree with the index of the area change of decayed tissues under theseconditions. As shown in Fig. 5, the pseudo-colors of decayed tissues at 53 hourwere darker than that at 46 hour. Hence, grey value corresponding to the pseudo-color images at different times was accumulated. As shown in Fig. 6 (b), the accumulative grey value curve indicated that the grey value at 53 hour was lighter than that at 46 hour. Therefore, the decay degree at 53 hour was more serious than that at 46 hour.

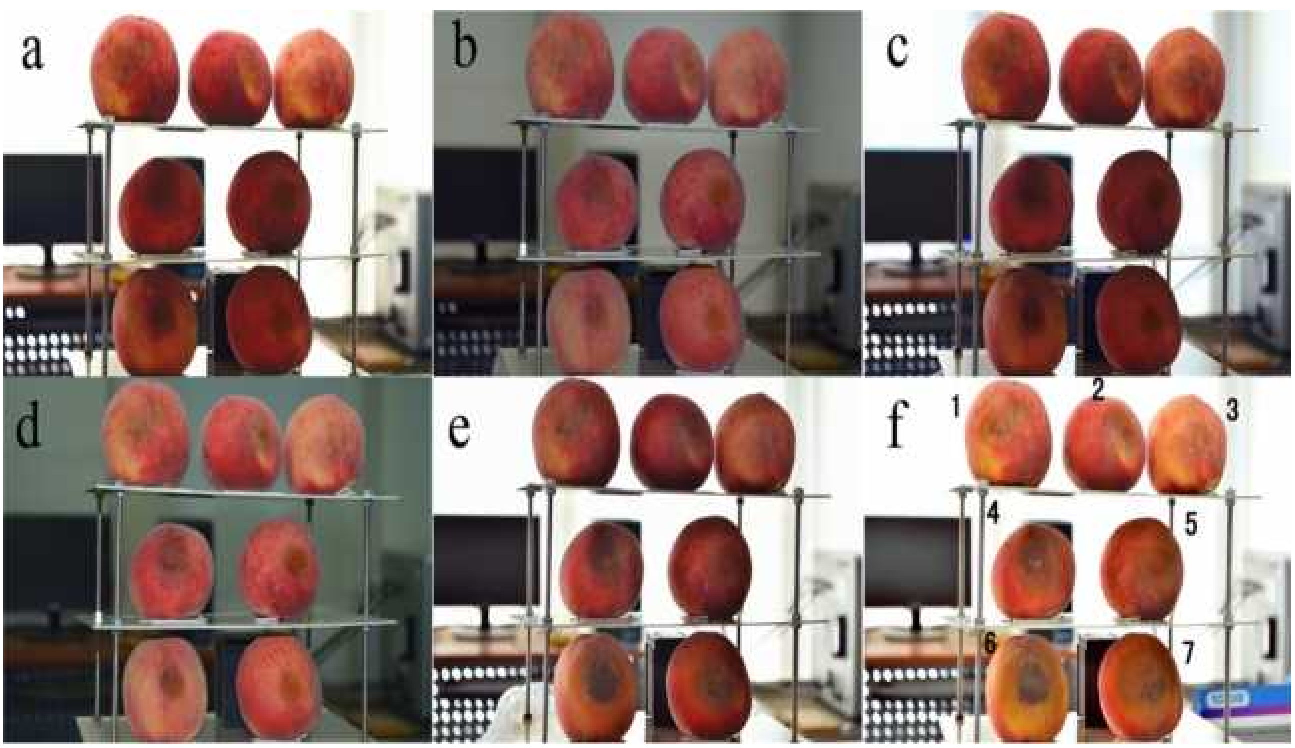

Fig. 2 Visible images of peach decayed process recorded by CCD camera at the different time: (a) 1 hour; (b) 7 hour; (c) 24 hour; (d) 32 hour; (e) 46 hour; (f) 53 hour.

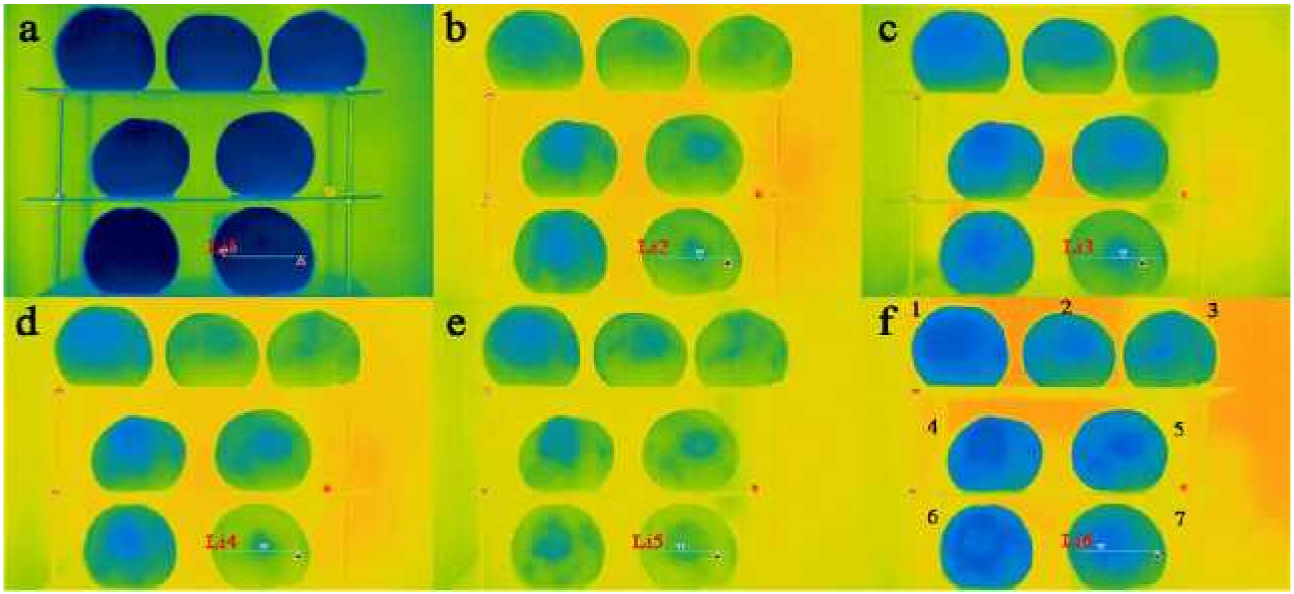

Fig. 3 Infrared thermal image of peach decayed process recorded by FLIR SC620 system at the different time: (a) 1 hour; (b) 7 hour; (c) 24 hour; (d) 32 hour; (e) 46 hour; (f) 53 hour.

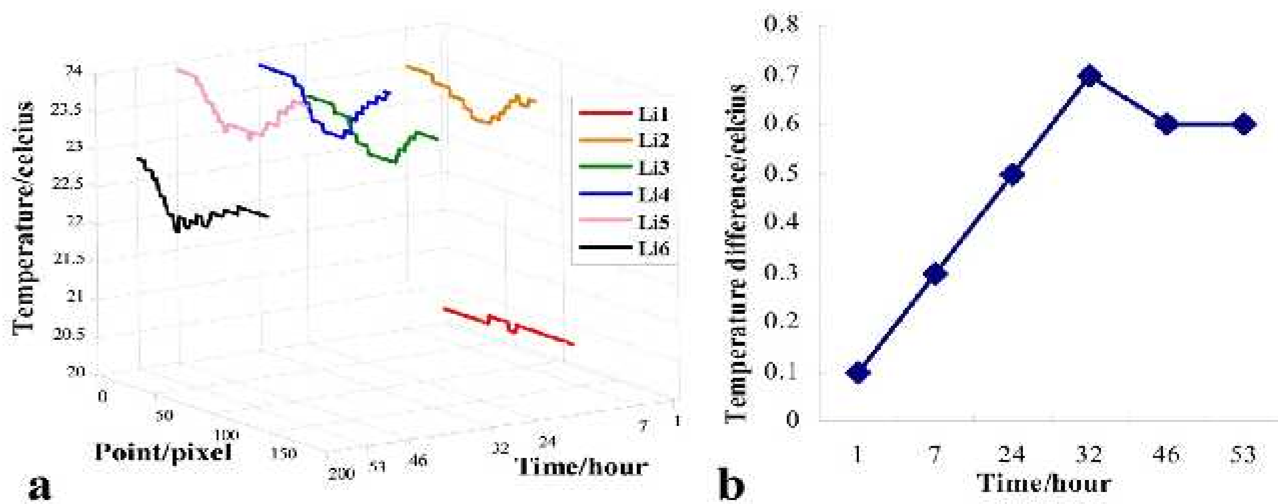

Fig. 4 (a) absolute temperature distribution of 125 pixels on the line covered the decayed and sound tissues at the different time; (b) absolute temperature difference between the decayed and sound tissues at the different time.

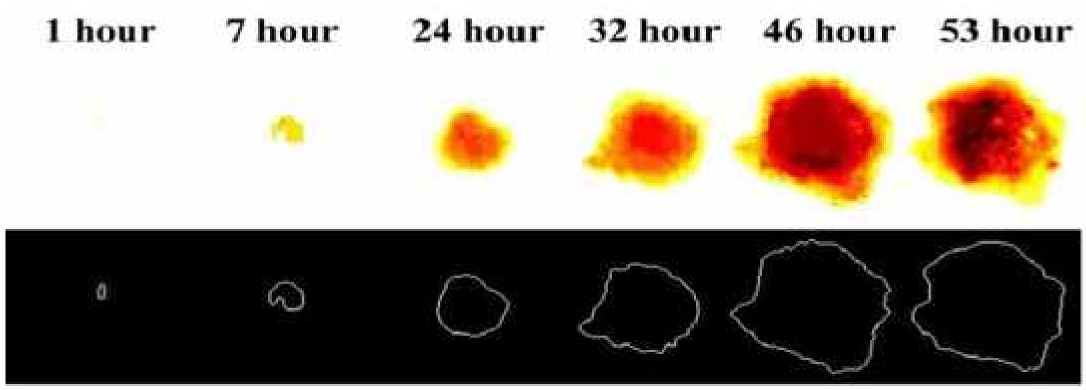

Fig. 5 Pseudo color images and edges of decayed tissue at different time during the decayed process.

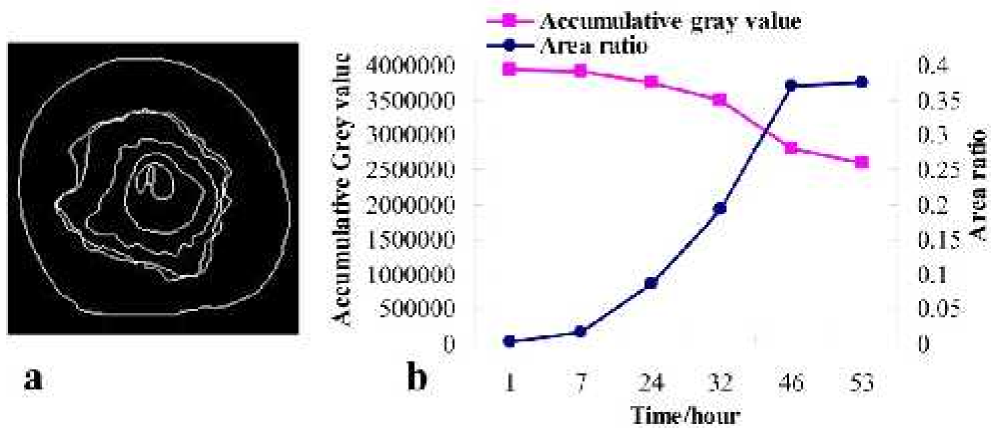

Fig. 6 (a) edge variation of decayed tissue within the peach edge at the different time; (b) area ratio of decayed tissue occupying the peach and accumulative gray value corresponding to the pseudo color images at the different time.

Conclusions: The surface absolutetemperature of the decayed tissues detected by the infrared thermal imager did not vary with the aggravation of the decayed degree because of the variation in environment temperature and measuring error of the FILR system. Therefore, it was not feasible to determine the decay degree with the peach's surface absolute temperature. Surface absolutetemperaturesbetween the decayed tissues and sound tissues showed significant differences, and the temperature difference gradually increased with aggravation of the decayed degree, before mildew grew. Therefore, the decay degree could be evaluated by the temperaturedifference between the decayed tissues and sound tissues. In order to eliminate the impact of environment temperature, the edge variation extracted from decayed tissues indicated that the area of decayed tissues increased significantly with the aggravation of the decay degree,until the decayed tissue began to mildew. Although the area of decayed tissues showed only small changes after mildewing, the pseudo-color difference was significant. A grey value corresponding to the pseudo-color image was accumulated, and the grey value of decayed tissues after mildewing was lighter than that before mildewing. This result indicates that the decay degree was more serious after mildewing. These conclusions were obtained under uncontrolled temperature conditions similar to a fruit shelf environment, so they can be used to develop a method for monitoring the fruit decay process and calculating the area of the decayed tissues.

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