NONDESTRUCTIVE DETECTION OF THE INTERNAL QUALITY OF APPLE USING X-RAY AND MACHINE VISION

Fuzeng Yang [1,2,*], Liangliang Yang [1], Qing Yang [1], Likui Kang [1]

[1] *College of Mechanical and Electronic Engineering, Northwest Agriculture and Forestry University, Yangling, China, 712100*

[2] *Department of Computer Science and Technology, Northwestern Polytechnical University, Xi'an, China, 710072*

[*] *Corresponding author, Address: College of Mechanical and Electronic Engineering, Northwest Agriculture and Forestry University, Yangling, 712100, P. R. China, Tel: +86-29-87092913, +86-13772025795, Email: yfz0701@163.com*

Abstract: The internal quality of apple is impossible to be detected by eyes in the procedure of sorting, which could reduce the apple's quality reaching market. This paper illustrates an instrument using X-ray and machine vision. The following steps were introduced to process the X-ray image in order to determine the mould core apple. Firstly, lifting wavelet transform was used to get a low frequency image and three high frequency images. Secondly, we enhanced the low frequency image through image's histogram equalization. Then, the edge of each apple's image was detected using canny operator. Finally, a threshold was set to clarify mould core and normal apple according to the different length of the apple core's diameter. The experimental results show that this method could on-line detect the mould core apple with less time consuming, less than 0.03 seconds per apple, and the accuracy could reach 92%.

Keywords: X-ray; machine vision; detection; apple; internal quality.

1. INTRODUCTION

Mould core of apple could be aroused by *Trichothecium roseum* and other factors (Zhang et al., 2008). The *fumaric acid* in apple juice increases

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dramatically from 0.8 to 2.6 due to the mould core (Yi et al., 2001). Therefore, it is necessary to detect the internal quality to guarantee the quality of apple reaching market.

In the past few years, there are many methods which have been proposed to detect internal quality of fruits and vegetables. Multi spectroscopy has been investigated for detecting the brown heart of pear (Zerbini et al., 2002; Han et al., 2006). Near-Infrared Spectroscopy (NIR) has been used for predicting sugar content of Apple (Ying et al., 2006). Ultraviolet (UV) fluorescence has been reported for detecting freeze damage of citrus (Slaughter et al., 2008). Researches has been done at using Magnetic resonance imaging (MRI) (Thybo et al., 2004), laser technique methods to measure fruit tissue texture and internal disorders (Muramatsu et al., 1999). X-ray technology has also been adopted for detecting the agricultural quarantine materials (Toyofuku et al., 2007), seed weevil-infested mango fruits (Thomas et al., 1995) and the edible ratio and sugar content of rambuta (Zhang et al., 2005). However, there is little report on the detection of mould core apple using X-ray. It is necessary to do research on detecting the apple's internal quality using low-cost X-ray instrument.

Furthermore, digital image processing algorithm is vital in detecting and extracting the image features, such as brown heart in pear (Zerbini et al., 2002; Han et al., 2006), stem-end injury in citrus (Blasco et al., 2007) and edible ratio and sugar content of rambuta (Zhang et al., 2005). The algorithms were focused on spatial domain in former researches. In recent two decades, Wavelet Transform (WT) from Multi Resolution Analysis (MRA) has been successfully used in image processing, which can detect the signal catastrophe point in spatial and frequency domain. The WT is known as the mathematic microscope (Daubechies, 1992; Yang, 2007). Ying et al. (2006) has used the WT de-noising NIR image of apple; the results showed WT can improve the de-noising effort. Yang et al. (2005, 2007) has done many researches in agricultural image de-nosing and enhancement, the results showed the WT is an effective algorithm in agricultural image processing. In 1990's Sweldens et al. provided the Second Generation Wavelet Transform – Lifting Wavelet Transform (LWT), which provides a quick and less memory needed algorithm in frequency domain (Sweldens, 1995, 1996). However, there are not any researches on agricultural image processing using LWT.

The objectives of this study are to:

(1) Construct a real time detection system to detect the internal quality of apple using X-ray.

(2) Determine a suitable image processing algorithm to extract image's features using lifting scheme wavelet in frequency domain, which could efficiently detect the mould core apple.

(3) Determine a processing method, using the (2) algorithm, can efficiently classify the apples with or without mould core, and determine its accuracy.

2. MATERIALS AND METHODS

2.1 Apple samples

One hundred apple samples were harvested in Mid-September 2007 from an orchard in Yangling, Shaanxi province of China and stored without any special instruments. The apples were transported to the laboratory in March 2008, and then stored in the room condition.

2.2 Instrumentation

The real-time internal quality detection system consists of two parts. The first part is an X-ray radiator (BJI-1U, Bo Jin Electronic Instrument, Inc., Shanghai, China) and a machine vision system, which includes a black and white (BW) camera (ECB-1793, Hong Tian Zhi Electronic, Inc., Shenzhen, China) and an image grabber (BS-602A, Bao Shi, Inc., Taiwan, China). The other is an X-ray image processing workstation (Itellistation Z Pro MT: 9228, IBM, New York) with the image processing program programmed by ourselves using the Matlab (MathWorks, Inc., Natick, Mass).

2.3 Detecting the mould core of apple

The prime purpose of the system is to determine whether the apple is a mould core apple. The success of the detection depends mostly on the correct image feature extraction. The following sections will focus on how to extract image features.

2.3.1 X-ray image processing algorithm

We proposed an effective algorithm that is used to detect the mould core apple in frequency domains inspired by the LWT.

2.3.2 Lifting scheme wavelet

A canonical case of lifting consists of three stages: split, predict, and update (Sweldens, 1995, 1996). It is simply described as follows.

Firstly, the signal λ_0 is divided in to two parts λ_{-1} and γ_{-1}.

Secondly, we use the λ_{-1} subset to predict the γ_{-1} subset based on the correlation present in the original data. If a prediction operator P can be found,

$$g_{-1} = P(l_{-1}). \tag{1}$$

If the prediction is reasonable, the difference will contain much less information than the original γ_{-1} set. We can denote this abstract difference operator as

$$g_{-1} := g_{-1} - P(l_{-1}) \tag{2}$$

In this way, the wavelet subset encodes how much the data deviates from the model on which P was built. Then split λ_{-1} into λ_{-2} and γ_{-2}, and replace γ_{-2} with the difference between γ_{-2} and $P(\lambda_{-2})$. After n steps, the original data is replaced by the wavelet representation $\{\lambda_{-n}, \gamma_{-n}, \cdots, \gamma_{-1}\}$. In order to solve the aliasing problem, the third step - update is introduced. Using an operator U and the already computed wavelet set γ_{-1} update λ_{-1} so that a certain scalar quantity Q could be obtained,

$$Q(g_{-1}) = Q(g_{-0}). \tag{3}$$

Therefore, we use the already computed wavelet set γ_{-1} to update λ_{-1} so that the latter preserves Q. In this way, an operator U can be constructed and updating λ_{-1} as

$$l_{-1} := l_{-1} + U(g_{-1}) \tag{4}$$

The original data could be decomposed as

$$l_0 = \sum_i l_i + \sum_i g_i, (i = -n \sim -1) \tag{5}$$

The above steps illustrate the basic idea of lifting. One property of lifting is that the inverse wavelet transform can immediately be found by undoing the operations of the forward transform. In practice, this comes down to simply reversing the order of the operations and changing each + to a - and vice versa.

2.3.3 Detection algorithm and its implementation

This section would analyze the image to determine the mould core apple. The original RGB (Red, Green, Blue; the native space for color representation in computers) image was converted to grayscale image before processing. The X-ray image could be transformed into a low frequency and three high frequency images by LWT. The low frequency image always represents the approximate character of the image, which can represent the original image with low noise, while the high frequency image always represents the noise and the points of discontinuity.

The procedure of the detection method is described as,

(1) Extract the low frequency image using LWT that represents the feature of the apple's image (Fig.1 (b), Fig.2 (b)).

(2) Enhance the image using histogram equalization in order to recognize the mould core (Fig.1 (c), Fig.2 (c)).

(3) Detect the apple's edge using Canny operator to get the apple core's diameter (Fig.1 (d), Fig.2 (d)), from which we can clearly obtain that the diameter of mould core apple is longer than the normal one's.

(a) original image (b) low scale image (c) enhanced image (d) edge detection image

Fig.1: X-ray images of a mould core apple

(a) original image (b) low scale image (c) enhanced image (d) edge detection image

Fig.2: X-ray images of a normal apple

(4) Calculate the diameter of the apple core by the statistical method - counting the pixels corresponding to the mould core (the pixel value is one in the binary image) in four directions (Fig.3), the algorithm is showed as the equation (6).

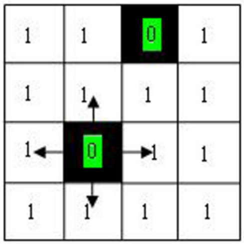

Fig.3: Four directions in the detection

$$m=\begin{cases} m+1, & pixel\ value=1 \\ m, & pixel\ value=0 \end{cases} \quad (6)$$

(5) Compare the value of m with the threshold that has been set to sort the apple, if m>threshold we can classify the apple to mould core apple, otherwise to good one.

3. RESULTS AND DISCUSSION

The results of this research are the development of a new online feature detection algorithm based on LWT, construction a detection system using machine vision and X-ray that can obtain the internal apple's image.

Table 1 shows the time consuming using different algorithms to detect the mould core. It illustrates that LWT is less-consuming than space domain method (contrast enhancement). We can clearly notice that the time consuming is less than 0.03 seconds by the frequency domain algorithm (LWT), which is quick enough to detect the quality in the on-line system.

Table 1. Time cost in different algorithms.

Time cost	Contrast enhancement	LWT (Wave name)				
		Haar	Db2	Db4	Lazy	9.7
1^{st}	0.1424	0.0235	0.0245	0.0287	0.0225	0.0269
2^{en}	0.1427	0.0229	0.0295	0.0276	0.0225	0.0265
3^{rd}	0.1427	0.088	0.0238	0.0274	0.0224	0.0263
Average	0.1426	0.0251	0.0259	0.0279	0.0225	0.0266

The unit of time cost is s.

Table 2 illustrates the detection results. The apple could be sorted at the accuracy of 92%. Generally, the failed detection is aroused when the apple did not sharply face the X-ray radiator.

Table 2. Detection results of the experiment.

Sample	Number	Detected	Undetected	Accuracy rate
Normal	72	69	3	92%
Mould core	28	23	5	

Overall, the results reveal that X-ray image is available as a non-destructive method used for detecting the apple's internal quality. Although this paper focused only on apple, the algorithm could also be used for pear, peach, pineapple and kiwi fruit. Moreover, the algorithm can be polished by other methods that need more study to promote its robust and accuracy.

4. CONCLUSIONS AND FUTURE WORKS

From the experimental results, the following conclusions can be drawn.

(1) The X-ray can obtain clear internal image of apple, which can be processed to detect the quality.

(2) Lifting wavelet transform is an efficient way to process the X-ray image, which can easily reduce the noise and enhance the image.

(3) The detection algorithm can quickly (less than 0.03 seconds per apple) and accurately detects the mould core apples, with an accuracy of 92% in the experiment.

The results of this research demonstrate the feasibility of an on-line X-ray based sensor for detecting internal quality of apple. In addition, the other works can be done at the automatic conveyor to push the internal quality detection to a new stage.

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