Computers and Electronics in Agriculture 151 (2018) 156–164

Contents lists available at ScienceDirect

Computers and Electronics in Agriculture

journal homepage: www.elsevier.com/locate/compag

Review

Review on the recent progress of non-destructive detection technology for internal quality of watermelon

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ARTICLE INFO

Keywords:
Non-destructive detection
Watermelon
Internal quality
Detection technology
On-line detection

ABSTRACT

It is important to classify the transportation, storage and sale of fruits according to the quality. But it is hard to detect the internal quality of watermelon and other big-sized and thick-skinned fruits with non-destructive means. Although non-destructive detection means of watermelon internal quality has been studied by many researchers, there are still few studies on the on-line detection equipment. Therefore, this paper reviews the recent progress of such type of research and summarizes the main techniques and methods for the detection of watermelon quality. What's more, it also analyzes the strengths and limitations in the application of the technique and introduces the status of the commercial on-line equipment and production line based on the existing technology. The direction in future is to develop portable and on-line detection equipment with multi-information fusion technology. This paper aims to enhance the manufacture of detecting equipment for the fruit quality.

1. Introduction

According to the statistics from UNFAO (United Nation Food and Agriculture Organization), watermelon (*Citrullus lanatus*) has been planted at approximately 100 countries and areas of the world (Tlili et al., 2011). There are 70 million tons watermelons yielded per year in the world, but the technology for fruit-commercialization is still lagging, especially for the grading of fruit in accordance with the internal quality. Due to lack of a classifying technique, fruit quality will be easily affected by mingled unripe and ripe varieties, which results in a poor competitiveness in the global market. Based on it, watermelon should be reasonably classified according to the quality before selling. Watermelon quality not only depends upon the figure, size and appearance, but also the maturity degree, sugar content, texture, pulp firmness, water content as well as internal defect (Kyriacou et al., 2016; Lv et al., 2015; Shiu et al., 2015; Soteriou et al., 2014). As a result, it is significant to detect the watermelon internal quality with non-destructive means.

As the computer and automatic detection technology grows fast, non-destructive detection technology for the fruit has been well developed in some developed countries recently while the study on the detection equipment are still at an preliminary stage in many countries. Although the equipment for fruit internal quality has been studied by many research institutions, the equipment for the thick-skinned watermelon are rarely reported (Zhang et al., 2014c).

This paper illustrates the study status and development of watermelon non-destructive detecting technology, providing references for studying non-destructive examination system to the quality of watermelon, even to the quality of thick-skinned melons so as to promote the manufacture of such system.

2. Non-destructive detection technology

According to different principles, non-destructive detection can be carried out by many means, such as acoustic properties, near-infrared spectroscopy (NIRS), machine vision, electronic nose, dielectric properties, nuclear magnetic resonance (NMR) and laser Doppler vibrometer (LDV) (Arendse et al., 2016; Fan et al., 2015; Gao et al., 2016; Nelson et al., 2007; Wang et al., 2016; Zhang et al., 2014a). Currently, many technologies have been studied and applied in the non-destructive detection of watermelon, and among these technologies, acoustic properties and NIRS have been most widely applied.

2.1. Acoustic property technology

Acoustic property is used in the non-destructive detection of

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https://doi.org/10.1016/j.compag.2018.05.031
Received 20 January 2017; Received in revised form 30 September 2017; Accepted 28 May 2018

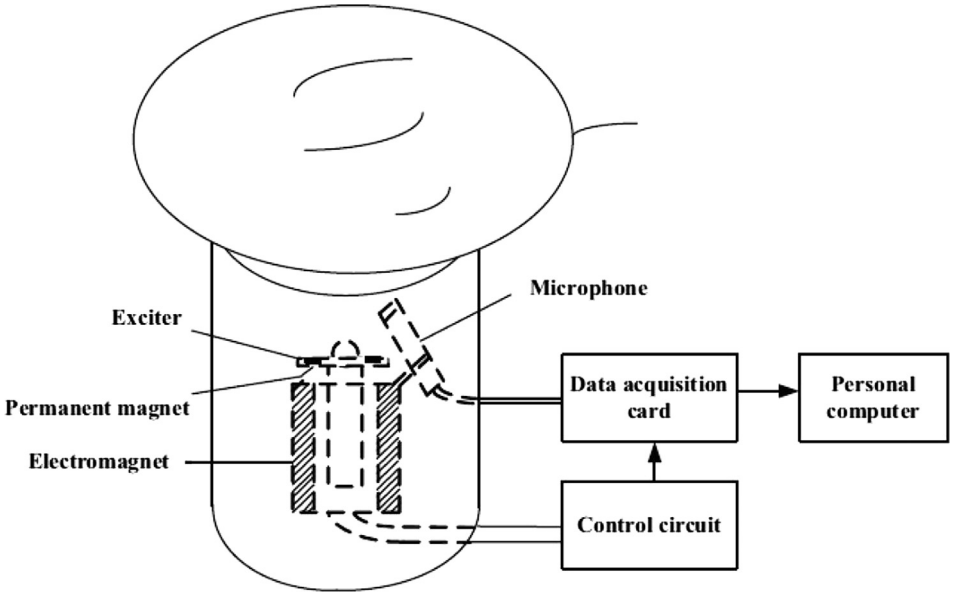

Fig. 1. Schematic of acoustic impulse response setup.

watermelon internal quality very early. Mutual interactions between fruit and sound waves are reflected in the acoustic transmission, scattering, absorption and reflection properties, attenuation coefficient, propagation velocity, acoustic impedance as well as natural frequency, and then non-destructive detecting of fruit quality is carried out (Wiktor et al., 2016). Detecting of watermelon internal quality with acoustic property mainly focuses on the maturity, internal defects, pulp firmness and sugar content, etc.

In recent years, with the emergence of the advanced instrument and new methodology, the study of the watermelon maturity with acoustic property has been greatly developed. Now the researchers have applied more algorithms to build classification models to analyze the correlation between the acoustic property and watermelon maturity. Baki et al. (2010) adopted mel-frequency cestrum coefficients (MFCC) and multilayer perceptron (MLP) neural network to study the maturity of watermelon. During the work, acoustic signals were collected and converted into MFCC coefficients that were then used to train a MLP. MLP presented an ultimate judgement on the watermelon maturity, with 77% accuracy rate. An acoustic device was developed after inspecting the effect of hitting ball and fruit tray to the spectrum (Fig. 1). Mao et al. (2016) found that there was an obvious correlation between firmness and firmness indices, such as f^2m, $MI1$ (index of the first order moment) and $MI2$ (index of the second order moment) using the model of linear regression and nonlinear model of back propagation artificial neutral network (ANN). It was concluded that the linear model was much more suitable than nonlinear model when using ANN method, and the correlation coefficient (r) of index $MI1$ was the highest with a value of 0.739 and 0.684 for calibration and validation set, respectively. Gao et al. (2010) considered that audio frequency band magnitude vector (BMV) was closely correlated to the maturity of watermelon, concluding that probabilistic neural network (PNN) algorithmic model had a better effect to the detecting of watermelon maturity, with 86% accuracy rate of classifying round melon and 91% of oval melon, respectively.

Portable instrument is always favored by the people. As mobile devices have increasingly played an important role in the daily lives, Zeng et al. (2014) tried to collect the acoustic signals generated from thumping watermelons with microphones on mobile devices (Fig. 2). They combined watermelon ripeness-related acoustic features with the feature vector to build a classification model, which was tested and confirmed to be able to correctly classify ripe and unripe watermelons at above 89% overall accuracy.

Firmness indicates ripeness of many agro-products, including melon, which is often determined by acoustic impulse method non-destructively (Taniwaki et al., 2010). Ikeda et al. (2015) developed a new acoustic technique called surface elastic waves for the evaluation of the texture firmness of watermelon flesh. By testing the propagation times of the surface elastic waves in fixed frequencies from 800 to 2400 Hz at different positions, gives the velocity, which along with knowledge of the Poisson ratio, yields the shear elasticity of the flesh. The surface-wave velocity of the samples had shown a decrease of 10.2% after ten days of storage.

During the harvest, packaging and transportation, watermelon is easy to be damaged internally because of extrusion and collision. Cracks and cavities in the pulp are likely to be caused from certain external force. Wei et al. (2012) developed a device used for testing the watermelon sugar content and hollowness, the results showed that the detecting effect might be better when percussion and signal receiving parts were located at the equatorial or umbilical part, r was 0.88, and the best part for detecting hollow watermelon was located at the equatorial part, with accuracy rate 79%.

To sum up, there have been numbers of scholars conducting a study on the internal quality of watermelon with acoustic property, and a great achievement has been made. However, most results were limited to the laboratory researches. Such method is characterized with low cost, high sensitivity and high adaptability, but it takes longer time and easily disturbed by the environment. It is hard to avoid the influence from surrounding noise and vibration to the signal. Though the researchers tend to optimize the correlation between the feature acoustic properties and internal quality of watermelon by modeling, these factors such as excitation positions and times, microphone distance, percussion angles and materials also largely affect the results of detection. As watermelon is large in size, its internal composition and structure are not uniform, and the transmittance of the acoustic waves in watermelon is not clear, it needs to carry on multipoint test to get all the internal information. Therefore, there are more practical problems of the acoustic technology application for on-line non-destructive detection system to the watermelon internal quality.

2.2. Near-infrared spectroscopy technology

Due to the differences in the fruit characteristic, such as sugar content and firmness, light transmission, absorption and reflection are different. The NIRS technology is the most widely applied in those