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Firmness prediction and modeling by optimizing acoustic device for watermelons

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ABSTRACT

Firmness can be used to indicate ripeness of many agro-products, usually determined by acoustic impulse method nondestructively. An acoustic device was developed after investigating the influence of hitting ball and fruit tray on spectrum. Three firmness indices such as f^2m, *MI*1 (index of the first order moment) and *MI*2 (index of the second order moment) were proposed to correlate with firmness of watermelon. Significant correlation was found out between firmness and these indices using linear regressive model and nonlinear model of artificial neutral network (ANN). It was concluded the linear model was more suitable than nonlinear model using ANN because of little difference of correlation coefficients. Although more computations needed, index *MI*1 was considered more precisely to use as firmness indices than f^2m in the case of splitting peaks with almost the same amplitude around the first resonant frequency.

1. Introduction

Although cultivated areas and production of watermelon in China reach above 50% of the world, a small part of them is exported because of inferior sorting and grading techniques for internal quality. Firmness is often used as one of textural indicators, and commonly determined by MT penetration test, in which an issue of a fruit is inserted into with a probe mounting on texture analyzer or universal testing machine at certain speed to some depth to obtain maximum force or slope of force–deformation curve in elastic stage, reflecting changes of ripeness of watermelon. However, it has disadvantages of tissue destruction and dependency on properties of the test point. Nondestructive techniques, especially acoustic/vibrational technique, can overcome the drawbacks of penetration test totally in firmness determination nondestructively and rapidly.

Every part of acoustic device can affect frequency spectrum. Mass of accelerometer sensor attached to the apples tightly influenced the amplitude ratio at 1000–400 Hz (Finney, 1970). Also the spectrum was affected by contact time between exciter and sample, which relied much on properties of exciter of acoustic device (Chen et al., 1992; Galili et al., 1998). Amplitude as well as the order of resonant frequency was varied in different tray and hanging style (Stone et al., 1996). Therefore, acoustic device optimization is helpful to determine resonant frequency accurately and reduce error as much as possible.

Lots of firmness indices were put forward because of satisfactory capability of ripeness prediction for fruits and vegetables. Stiffness coefficient f^2m was proposed by Abbott et al. (1968) to evaluate firmness of apples, and later modified into $f^2m^{2/3}$ called elastic coefficient (EI) by Cooke and Rand (1973), which was confirmed mathematically and practically significant relationship with Young's elastic modulus. It had been successfully used to estimate ripeness of many agro-products, such as mango (Raju et al., 2006), pear (Taniwaki et al., 2009), apple (Belie et al., 2000). Some researchers tried to determine firmness of watermelon by acoustic impulse technique, but weak correlation was found with the indices mentioned above, probably because it is characterized by thick rind, big volume and non-uniform internal components (Yamamoto et al., 1980). Other acoustic parameters, e.g. band magnitude (BM) were used and proved more effective to discriminate void watermelon from good ones rather than firmness prediction (Diezma-Iglesias et al., 2004). Predictive precision depends not only on the selection of acoustic characteristic parameter but also on the selection of modeling method. Linear modeling techniques, especially unary linear regression (ULR), partial least square regression (PLSR), stepwise multiple linear regression (SMLR), are extensively used in quality evaluation of many fruits (Taniwaki et al., 2010; Rubio-Diaz et al., 2011; Jonesa et al., 2010). Another modeling technique is artificial intelligence (AI) techniques such as artificial neural network (ANN), simulating structure and

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behavior of human brain and characterizing by parallel computation, self-learning, and self-organization. It is often applied in the field of function fitting and optimization, feature extraction and pattern recognition etc., particularly adapt to modeling of nonlinearity and black box system in the last decades (Maleki et al., 2013).

Little desirable results are available on firmness prediction of watermelon using acoustic impulse technique, so the objectives of the research were as follows: (i) to investigate the effect of hitting ball, tray on frequency spectrum for acoustic device optimization, (ii) to construct linear regression and ANN models between acoustic firmness indicators and firmness of watermelon.

2. Materials and methods

2.1. Samples

A batch of 'Kylin' watermelons was collected in July, 2014 at the local watermelon planting greenhouse in Hangzhou, China. Samples at different ripening stage were attentively chosen by melon experts, and those with bruise or crack in appearance produced in the process of carrying and transportation were removed prior to test. Rest of 114 watermelons were kept and used. Fourteen samples were used to study the effect of hitting ball and tray on spectrum of acoustic response. Another 100 samples were divided into two groups: calibration (59 samples) and validation set (41 samples). All samples were stored at room temperature (ca. 25 °C) throughout the measurement.

2.2. Acoustic detecting device

Acoustic device mainly consists of exciter, condenser microphone, data acquisition card (DAQ card), control circuit and desktop computer, as shown in Fig. 1. When driven by control circuit, the electromagnetic force was produced with direction opposite to the force of permanent magnet fixed on the upper of exciter. Then exciter was pushed to hit the watermelon with a hitting ball on the top. The acoustic impulse response was gathered by a 1/2″ pre-polarized condenser microphone (G.R.A.S 40PH, National instrument Co. Ltd., Beijing, China) and transferred to computer after digitalized through a 24-bit DAQ card ((NI9234, National instrument Co. Ltd., Beijing, China) with sampling rate of 51.2 kbps. Acoustic response with duration of 0.2 s was then transformed into frequency domain by FFT. The first resonant frequency was drawn from spectrum through self-compiled program based on 'Matlab 2014a (The Mathworks, Inc., USA)'.

The typical acoustic signal in time domain and normalized magnitude spectrum can be seen in Fig. 2. Due to very small amplitude of high frequency component in the spectrum, frequency band 0–500 Hz contained most information reflecting ripeness and would take into account to reduce noise and computations.

2.3. Universe testing machine (UTM)

Compression test is a common quasi static method, which is frequently used in nondestructive firmness measurement for agro-products, and is conducted by universal testing machine. A sample was placed on the static platform of UTM (CMT 4204, MTS systems Co., Ltd., China) first, with its short axis vertical to crosshead uprights and long axis resting on a static flat platform. The load cell, connecting to crosshead of UMT, moved down to compress the sample on the equator with travelling speed of 5 mm/min and maximum deformation of 10 mm. Force–deformation curve was recorded by built-in data acquisition program, and force/deformation ratio of the curve at the bio-yield point was extracted as firmness of watermelon (Batu and Thompson, 1993; Diezma-Iglesias et al., 2006).

2.4. Instrument optimization

Three different hitting balls made of stainless steel, glass and rubber were applied to find out whether material of hitting ball affected the acoustic response. All of the balls were 16 mm in diameter in different elasticity modulus, and wouldn't be replaced by another until all 14 watermelons were finished testing.

The effect of material of fruit tray was studied using two different materials: polypropylene plastics and natural rubber. These two trays were designed specifically in the same dimension except material, and wouldn't be replaced by another until all 14 watermelons were finished testing.

Each of 114 watermelons was hitting at four positions evenly distributed on the equators. Average of the four recordings was used.

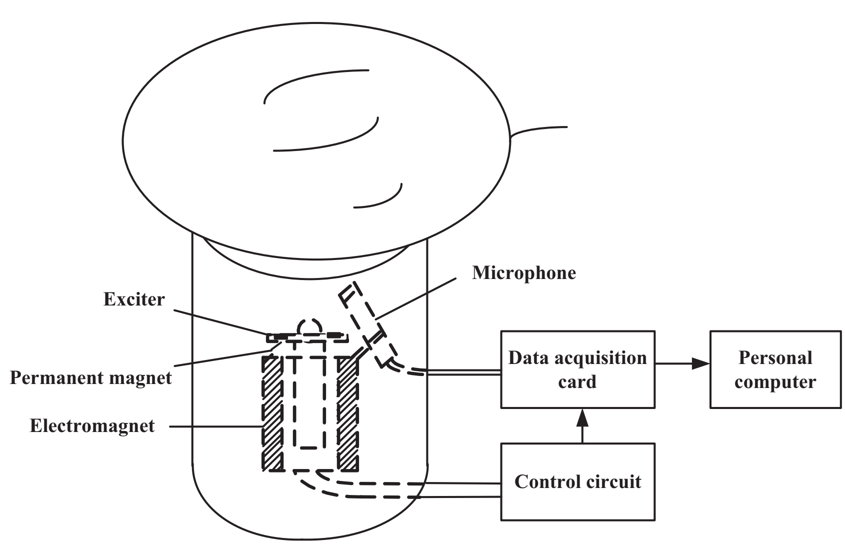

Fig. 1. Schematic of acoustic impulse response setup.