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On-line detection of eggshell crack based on acoustic resonance analysis

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ABSTRACT

An on-line system based on acoustic resonance was developed for eggshell crack detection. The system employed digital signal processing (DSP) as core processor to collect and analyze the response signal of shell eggs. The effects of excitation point, speed of the conveying system, impact intensity and egg mass on the frequencies response signals were investigated. Based on previous experiments, differences between the signals of intact eggs and cracked eggs were analyzed. Five excited resonance frequency characteristics expressing the differences between intact and cracked eggs were explored as input vectors. A simple and robust calibration model was built to discriminate intact and cracked eggs, while meeting speed requirement of on-line measurement. The identification rates for intact and cracked eggs were 100% and 96.1% respectively. It is concluded that the system has significant potential in the on-line detection of cracked eggs.

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1. Introduction

Egg as a well-popular and nutritious food in the daily human diet is considered to be a cheap source of quality protein (Adesiyun et al., 2006; Liu et al., 2007; Papadopoulou et al., 1997). Cracks on eggshell are commonly produced during packing and/or transportation. Cracked eggs are more vulnerable to *Salmonella* and other bacterial infections leading to health hazards (Adesiyun et al., 2005a,b). In addition, intact eggs might be contaminated with infected cracked eggs which usually results in significant economic loss (Bain, 1990). Crack detection in egg sorting and packing industry is usually achieved manually and relies on candling (Lin et al., 1995).

The technique of computer vision was employed to inspect appearance feature of the eggshell. A sequence of three images per egg was sufficient to identify over 90% of egg with cracks (Goodrum and Elster, 1992). Jenshin et al. (2001) developed an automatic detection system for eggshell. The identification rates of intact eggs and cracked eggs were 86% and 80%, respectively. However, the detection result was affected by the resolution of the camera, the classification algorithm, the color and the surface condition of the shell and the type of defect. Especially, it is difficult to detect fresh crack and hairline crack.

Measuring and analyzing the mechanical behavior of the eggshell is another method for eggshell crack detection (Moayeri, 1998). The amplitude and number of the rebounds produced by impacting on the eggshell were analyzed to acquire the indication for the local mechanical eggshell integrity. Multi-impact (24–32 points per egg) was carried out to detect the crack on the eggshell. The crack detection rate ranges from 70% to 85% while the percentage falsely rejected intact eggs is between 0.3% and 1%.

Recent researches have shown that it is possible to measure the quality of eggs by analysis of the dynamical frequency response of eggshells (Cho et al., 2000; De Ketelaere et al., 2000). De Ketelaere et al. (2003) evaluated several parameters for eggshell measurement. Jindal and Sritham (2003) employed ANN (artificial neural network) model combined with acoustic resonance to detect cracked eggs. The mechanical properties of rupture force, specific deformation, rupture energy and firmness was examined (Altuntas and Sekeroglu, 2008). It was found that the acoustic response signals of eggs were affected by impacting locations and force (Nedomova et al., 2009a,b). Lin et al. (2009a,b) developed an experimental system combined with supervised recognition pattern to discriminate intact and cracked eggs, and employed support vector data description to solve the problem of imbalanced training numbers. Principal component analysis (PCA) was used to extract features from response signals, and linear discriminant analysis (LDA) was adopted to discriminate cracked eggs. Intact egg and cracked egg could be distinguished by using the features of maximum magnitudes in turn (HVM) and frequencies by magnitudes in turn (MVF) (Zhao et al., 2010).

This work intends to develop an on-line system for automatic and rapid detection of eggshell cracks. DSP was employed to and analyze the acoustic response signal, which produced from the impacting on eggshell. Some influencing factors on dynamic resonance frequency such as; excitation point, egg mass, speed of the conveying system and impact intensity were also investigated.

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The characteristics of response signals expressing the differences between intact and cracked eggs were explored and then a simple and robust model was employed to build identification model.

2. Material and methods

2.1. Samples preparation

A total number of 603 fresh eggs were investigated. All eggs were collected from a poultry farm. In order to ensure the reliability of the samples, the methods of visual inspection and acoustic detection by manual were employed to inspect all samples. External pressure was imposed on the detected eggs while candling. These eggs were stored at room temperature for 3 days and its dimensions were measured. The sizes of the eggs were from peewee to jumbo and the mass ranged from 53.25 to 67.54 g, with an average of 58.2 g. Irregular eggs were not incorporated in the data analysis.

2.2. Experimental system

On-line system based on acoustic resonance comprises of a roller conveying system, an exciting set, a mini microphone, a signal conditioning circuit, digital signal processing (DSP) and a computer (PC).

The roller conveying set consists of pairs of hard rubber rollers, which were used to support the eggs and to roll them forward. The shape of the support was focused to normal eggshell surfaces. The speed of the conveying system ranges from 28 to 45 cm s^{-1}.

The excitation set includes an infrared trigger set, an electromagnetic driver, an adjustable DC (direct current) power supper and a light metallic stick. The total mass of the stick is 6 g and its length is 6 cm. The adjustable DC power supper was used to control the excitation force, which is an important factor that affects the magnitude and the width of the pulse. Based on previous test, the voltage of excitation was set at 24 V. At this voltage, optimal signals were achieved without overload. A mini condenser microphone (TL-97K, Enpin Tianlang Co. China) with sensitivity range of -46 ± 3 dB and response frequency between 80 and 12,500 Hz was employed for acoustic signal acquisition.

Response signals obtained from the microphone were amplified and filtered by signal conditioning circuit. A band-pass filter was used to preserve the information of the frequency band between 1200 and 6800 Hz. This is because, the features of the response signals were legible and the signal-to-noise was favorable in this frequency band.

The analog response signals were captured by a 12-bit analog-to-digital converter in DSP. The data acquisition program was compiled based on Code Composer Studio (CCS) in the computer, which is the environment to build and debug embedded real-time software application. It allows a fast acquisition and processing of the response signals. The sampling rate was 38 kHz. The time domain signal was transformed to a frequency signal by using a 512-point Fast Fourier Transformation (FFT).

In order to provide an intuitive and convenient operation for consumers, an operation interface for discrimination of cracked eggs was compiled by Visual Basic (VB).

A set-up of the system is presented in Fig. 1. The roller conveying set drives egg rolling forward. When an egg passes by excitation set in the system, the infrared light between transmitter and receiver is blocked. The infrared set outputs a high level to the external interrupt pin of micro controller unit (MCU). Then a DC motor with a metallic stick, which controlled by MCU and an electromagnetic driver circuit, conducts a mechanical impact on eggshell. Meanwhile, DSP is also triggered to acquire the response signal. In the soft, an endpoint detection algorithm was employed to identify the start of the acoustic signal. In order to shield disturbance signal from environmental, the microphone is placed in an enclosed space and connects with the stick. The acoustic signal was captured by the microphone in the form of analog signal; the signal was amplified and filtered by an electrical circuit and was converted to digital signal by DSP board; the computer can recorded and restored the signals through CCS for onward processing and analysis.

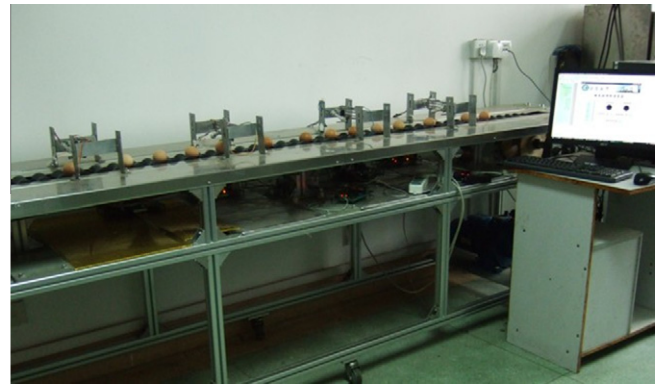

Fig. 1. Eggshell crack on-line measurement system based on acoustic resonance analysis.

2.3. Experiment procedure

Detection of eggshell cracks was carried out in the on-line acoustic resonance system. There were three steps for the detection. The first step was designed to investigate some influencing factors on dynamic resonance frequency for structuring a stable and reliable detection system. The second step intended to build a simple and robust calibration model for crack detection. Characteristics of response signals were extracted from 200 intact eggs and 200 cracked eggs. The cracks were inflicted around the equator of shells, and the cracked region could be detected by random excitation. The last step was aimed at testing the robustness of identification model. 100 intact eggs and 103 cracked eggs were investigated. The cracks were inflicted randomly on the eggshells. They were parallel, vertical or at an angle with the egg equator. Impacting position was placed randomly around the eggshells. For each egg, multiple times of impact were explored on the shells during the on-line crack detection. Once the cracked egg was identified, the number of impacts on the egg shell could be counted as well. According to previous experiments, when an egg was consistently identified as intact with the number of impacts over 40, it was classified as intact egg.

3. Result and discussion

3.1. Frequencies response under different factors

3.1.1. Excitation points

The top view of an egg laid on the support rollers was shown in Fig. 2. An egg was segmented by several small regions. Favorable response signals could be achieved when excitation was operated in labeled regions. Fig. 3 shows the frequency response signals with exciting point placed inside and outside the labeled regions. Great differences between these two signals were observed.

The first peak frequency (maximal magnitude value of frequency domain signal) was prominent and steady when exciting inside the labeled regions. In contrast, when exciting outside the

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