Journal of Food Engineering 153 (2015) 53–62

Contents lists available at ScienceDirect

Journal of Food Engineering

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

Eggshell crack detection based on the time-domain acoustic signal of rolling eggs on a step-plate

Cheng Jin, Lijuan Xie, Yibin Ying *

College of Biosystems Engineering and Food Science, Zhejiang University, Hangzhou 310058, China
Key Laboratory of Equipment and Informatization in Environment Controlled Agriculture, Ministry of Agriculture, China

ARTICLE INFO

Article history:
Received 28 August 2014
Received in revised form 20 November 2014
Accepted 10 December 2014
Available online 17 December 2014

Keywords:
Acoustic
Eggshell crack detection
Step-plate
Mahalanobis distance
ROC
AUC

ABSTRACT

Crack in the shell of eggs was detected by rolling eggs on a plate that had seven steps. This produced seven separate acoustic signals to produce characteristic vectors. The vectors from intact and cracked eggs were analyzed using the Mahalanobis distance so that intact and cracked eggs could be separated. The receiver operating characteristic curve and area under curve were employed to determine the discrimination threshold and optimize the step number – in this case being six. The analysis indicated that the method proposed in this paper could detect 90% of the cracks with a 10% false rejection.

1. Introduction

Eggshell crack increases the risk of bacterial pollution to eggs and the food safety risk for human. So far, one of the most extensively studied techniques for eggshell crack detection is based on analysis of acoustic signal. Researchers have developed two major structures for sound production: one with impacting force perpendicular to knock arm (Fig. 1A, De Ketelaere et al., 2000) and the other along the knock arm (Fig. 1B, Li et al., 2011). Although differences existed, both of them require egg rolling devices, egg position sensors and impacting control systems. For reaching higher crack detection (detected cracked eggs/all cracked eggs), several impacting devices are installed along a production line to impact as many positions on eggshell surface as possible (Fig. 1, Sun et al., 2013). Detection systems designed with these two structures have strong controllability on impacting but expensive and complex. As a result, simplification and cost reduction of device structure are treated as very important research aspects.

Devices based on these two structures were also used in discrimination algorithm tests. Principal component analysis, linear discriminant analysis (Zhao et al., 2010), multiple regression and discriminant (Cho et al., 2000), artificial neural network (Jindal and Sritham, 2003; Lin et al., 2010; Pan et al., 2011), support vector data description (Lin et al., 2009a), supervised pattern recognition (Lin et al., 2009b), wavelet-based signal analysis (Li et al., 2012), support vector machine (Deng et al., 2010; Xiong, 2011) and other self-defined algorithms (Wang and Jiang, 2005; Li et al., 2011; Sun et al., 2013) were reported. These algorithms all had crack detection over 90% and false rejection (wrongly classified intact egg/all intact eggs) below 10%. According to the evaluation standard of De Ketelaere et al. (2004), they were all excellent discrimination algorithms. Although the crack detection and false rejection of these algorithms were stated in detail, it was hard to compare with each other only by these two indexes and evaluate the characteristic vectors of an algorithm were suitable or not. So a more reasonable evaluation method was needed to judge every algorithm more generally.

Besides, researchers have studied lots of algorithms, but there is little improvement on the device. Presently, only replacing the microphone with the piezoelectric sensor has been reported (Wang and Jiang, 2005). However, this simple change did not improve the detection performance and it was difficult to keep the sensor on eggshell closely.

This study was aimed to propose a simpler and cheaper crack detection method to solve the disadvantages mentioned above. Specific objectives of this research were to:

* Corresponding author at: College of Biosystems Engineering and Food Science, Zhejiang University, Hangzhou 310058, China. Tel./fax: +86 571 88982885.
E-mail address: yingyb@zju.edu.cn (Y. Ying).

http://dx.doi.org/10.1016/j.jfoodeng.2014.12.011
0260-8774/

Symbols and abbreviations

DAMD	Discrimination analysis based on Mahalanobis distance
ROC	Receiver operating characteristic
AUC	Area under curve
DT	Discrimination threshold
TPR	True positive rate true positives/(true positives + false negatives)
FPR	False positive rate false positives/(false positives + true negatives)
$G_{prediction}$	The matrix of characteristic vectors of all eggs in the prediction set
G_{intact}	The matrix of characteristic vectors of intact eggs in the training set
G_{crack}	The matrix of characteristic vectors of cracked eggs in the training set
$G_{intactp}$	The matrix of characteristic vectors of intact eggs in the prediction set
G_{crackp}	The matrix of characteristic vectors of cracked eggs in the prediction set
G_1 & G_0	Two classes of a discrimination
Σ_1	The covariance matrix of G_1
Σ_0	The covariance matrix of G_0
$W(x_i)$	The difference of two Mahalanobis distances of x_i
x_i	An sample in the G_1 or G_0
μ_1	The mean value of the G_1
μ_0	The mean value of the G_0

- Produce acoustic signals for eggshell crack detection by rolling eggs on a seven step-plate.
- Use the DAMA based on the acoustic signals to discriminate the intact and cracked eggs and determine the discrimination threshold of this method by the ROC curve and AUC.
- Optimize the step number according to the comparison of ROC curves and discrimination results at different step number.

2. Materials and methods

2.1. Eggs samples

A total of 240 fresh eggs without irregular appearance and crack were selected by human inspection as the samples of this experiment. Half the eggs were artificially cracked by light mechanical impacts on the location near the eggshell equator. These impacts were made by a glass stick. The crack was normally invisible under human eyes. There were mainly two types of cracks: crack perpendicular to (Fig. 2A) and along (Fig. 2B) the egg equator. Each crack had only one main gap (Fig. 1). No crack extended to the blunt or sharp end of egg. All cracked eggs preserved their shapes and no egg content leaked.

Sixty intact and the same number cracked eggs (G_{intact} and G_{crack}) composed the training set to confirm the discrimination threshold of the DAMA. The rest eggs ($G_{intactp}$ and G_{crackp}) were considered as the prediction set ($G_{prediction}$) to test the confirmed discrimination threshold.

2.2. Detection device and procedure

A plate with seven steps (Fig. 3b) was placed on two soft supports (Fig. 3e) at an inclined angle of 5°. An electret microphone (Fig. 3a) was installed on the central back of the plate to collect sound signals made by eggs rolling down steps. The obtained sound signal was amplified by an amplifier (Fig. 3c) and then inputted to a computer (Fig. 3h). A 12V DC source (Fig. 3d) supplied power for the microphone and amplifier. The width of the plate was 100 mm and the length was 240 mm. The height of each step was 2 mm and the width was 33 mm.

The egg was kept still on the top of the plate before being detected. Then, it was released and rolled down the plate freely. Once egg passed a step, an impacting sound signal would be made. After rolling down the whole plate, detected egg (Fig. 3g) landed in a soft plate (Fig. 3f) which could protect the egg from damage and prevent the noise after detection.

De Ketelaere et al. (2000) reported that comparing similarity of frequency spectrums of four impacts on the eggshell equator apart 90° could detect eggshell crack. This principle was applied in this research. Because the average perimeter of egg equators in this experiment was about 132 mm, the width of each step was set 33 mm, a quarter of the perimeter. The characteristic of crack signal appearing every 3 impacts indicated that the crack was impacted twice just when the egg rolled one round (Fig. 3B, b and f).

Amplified signal was separated into seven parts (Fig. 4a–g). A threshold of 0.1 decided the beginning of separation. Once signal

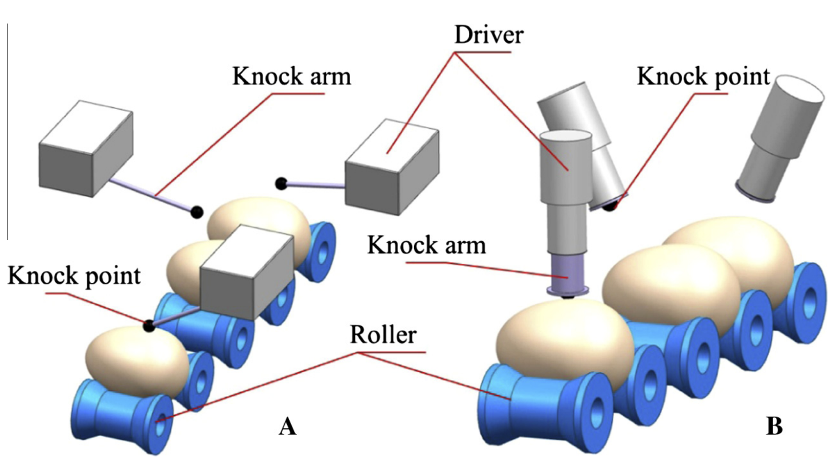

Fig. 1. Two structures of sound production devices.