Computers and Electronics in Agriculture 142 (2017) 429–439

Contents lists available at ScienceDirect

Computers and Electronics in Agriculture

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

Original papers

Sequenced wave signal extraction and classification algorithm for duck egg crack on-line detection

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ARTICLE INFO

Keywords:
Crack detection
Sequenced wave signal extraction and classification algorithm
On-line detection
Duck egg
Salted duck egg

ABSTRACT

A method to detect the shell cracks in translucent images of duck eggs and salted duck eggs is presented. The method consists of a sequenced wave signal extraction algorithm to extract the sequenced wave signals from the translucent images of duck eggs. Furthermore, the characteristic parameters of the extracted sequenced wave signals are calculated and analyzed. The analysis results showed that, the sequenced wave signals extracted from egg translucent images are caused by three factors: (i) egg cracks; (ii) air cell membrane of eggs; and (iii) shell texture. The sequenced wave signals caused by egg air cell membrane and shell texture are eliminated by using characteristic parameters of the sequenced wave signals. After the elimination, a classification algorithm is used on the translucent images of eggs. In the conducted experiments, the classification algorithm achieved an accuracy of 92.5% and 93.1% for duck eggs and salted duck eggs, respectively.

1. Introduction

Duck egg is an important table egg with the second largest consumption all over the world. Although hen egg occupies a significant percentage of the egg market in America and Europe, global production of other kinds of bird eggs, which is primarily duck egg (Huang and Lin, 2011), is increasing. According to recent data, duck egg production reached 5.73 billion tons in 2014 (FAO Statistics Division, 2014; Arthur et al., 2015). Duck egg is popular in Asia, and occupies 30% of the total egg consumption in China and Southeast-Asian countries (Pingle, 2009). Due to the fishy smell and problems with storage, duck egg is usually consumed as a processed egg. Salted duck egg has over a thousand years of history, and is one of the main kinds of processed duck egg. Salted duck eggs have higher nutrition value and better lifespan compared to unprocessed duck eggs (Fu and Su, 1997; Ganesan et al., 2014).

During transportation and sale of duck egg, shell of an egg can crack. A cracked egg gets infected easily by microorganism and become unsafe for consumption (Widdicombe et al., 2009). Therefore, the cracked duck eggs need to be detected and filtered-out before they enter the market. The industrial production process of salted duck eggs consists of following steps, washing of raw egg, grading of raw egg, crack detection of raw egg, salting, crack detection of salted egg, packaging, and steaming or boiling. Raw duck eggs need crack detection as any cracks in shell of duck eggs may cause safety issues, and the salting process will not be precise. Salted duck eggs also need crack detection before steaming or boiling, because the albumen of a cracked salted duck egg will flow out from the crack during steaming or boiling. This can result in a loss of market value. Therefore, duck eggs need crack detection both before and after the salting process. Mechanization and automation of duck egg industry is still in its infancy and even today, the cracked duck eggs and salted duck eggs are detected manually.

Egg crack detection methods have been studied for many years. Acoustics based and computer vision based methods for egg crack detection are the two well researched topics.

The acoustics based method for crack egg detection uses the inherent frequency difference between cracked eggs and intact eggs. Wang et al. (2004) detected the damaged duck eggs using the knocking acoustic signal and fuzzy recognition, and this method was shown to achieve an accuracy of 95%. Ding et al. (2006) designed the hardware and the software systems of knocking equipment for collection and classification acoustic plus signal of duck eggs. Later, Mei et al. (2011) optimized the knocking equipment, and made it suitable for on-line detection. Sun et al. (2013) designed an on-line detection equipment for hen eggs based on acoustic resonance analysis. In addition to using the knocking acoustic signal, the acoustic signal of a free egg rolling on a step-plate was also used to detect the cracked eggs, and this method was shown to reach an accuracy of 90% (Jin and Ying, 2014; Jin et al., 2015).

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http://dx.doi.org/10.1016/j.compag.2017.09.034
Received 16 April 2017; Received in revised form 11 September 2017; Accepted 23 September 2017
Available online 29 September 2017

The computer vision based method for cracked egg detection uses the color or gray level change caused by cracks in the translucent image of an egg. The threshold-segmentation method is the most commonly used in computer vision based method for egg crack detection. Patel et al. (1998) extracted the histograms of the RGB components of the translucent image of an egg to build an artificial neural network to recognize the damaged eggs, and this approach was shown to achieve an accuracy of 87.8%. Xiong and Wang (2009) used thresholding and segmentation of the suspected crack regions from the translucent images of duck eggs, and classified them using their geometric parameters. Omid et al. (2013) developed an expert egg grading system based on machine vision for grading and crack detection of hen eggs. When detecting an egg crack, the expert egg grading system was used to perform thresholding and segmentation of the suspected crack regions from translucent image. Using the ratio between the area of suspected crack and the area of whole egg on the translucent image, cracked eggs were detected. Yang et al. (2014) used threshold-segmentation method to segment the suspected crack regions of eggs, and classified the cracked eggs and intact eggs using support vector machine and back-propagation artificial neural network models. However, it is hard to use threshold-segmentation method to perform segmentation of all the crack areas from the translucent image of eggs, because a small crack cannot create obvious high-light region on the translucent image. Therefore, crack-amplifying method using negative pressure before performing detection was studied. Lawrence et al. (2008, 2009) and Jones et al. (2010) used a negative pressure box to amplify the crack of a hen egg without creating new cracks. Next, the translucent image of the egg was captured and threshold-segmentation method was used to perform segmentation of the crack region to detect the cracked eggs. Yoon et al. (2011) developed a noise-reduction algorithm to decrease the image noise caused by relative movement between eggs and camera. Li et al. (2012) used a negative pressure box to amplify an egg crack, and then egg diffuse reflecting image was captured. An edge-extraction algorithm was applied to extract the crack areas from the captured image.

The acoustics detection method based on the knocking acoustical signal for crack egg detection has been well developed, and is currently being used in automatic fresh egg processing lines. Even though the computer vision based detection methods have advantages over the acoustics based detection method in terms of having a simpler structure and lower cost, the computer vision based methods have not been well developed and tested sufficiently to be used in on-line detection of egg cracks. Most of the existing research related to egg crack detection using computer vision technology is based on the threshold-segmentation method. However, due to the light transmission difference of different eggs, regions in the translucent images of eggs corresponding to egg cracks do not have uniform gray level. Hence, it is difficult to perform segmentation of the crack regions from translucent images of eggs. This drawback limited the applicability of the threshold-segmentation method in practice. The computer vision based detection method which used a negative pressure box to amplify egg cracks was shown to achieve better detection accuracy. Nevertheless, the structure of the detecting device was complex, and could not be used to perform continuous detection. Hence, a better computer vision based algorithm for egg crack detection needs to be developed.

In this study, a sequenced wave signal extraction algorithm for extracting crack information from the translucent images of eggs is developed. The algorithm uses the gray level difference between an egg crack and the region beside the crack in the translucent image of the egg. Furthermore, the proposed sequenced wave signal extraction algorithm is used to extract the suspected egg crack signals from translucent images of duck eggs and salted duck eggs. Furthermore, a sequenced wave signal classification algorithm is proposed to distinguish the sequenced wave signals caused by egg cracks from those caused by other influence factors. Finally, a new method for on-line egg crack detection of duck eggs and salted duck eggs based on the sequenced wave signal extraction and classification algorithm is proposed and verified experimentally.

2. Material and methods

2.1. Samples

Freshly laid duck eggs, less than 3 days old, were bought from Tongwei Road farmers market, Nanjing, Jiangsu province, China, and transported to our laboratory. After the cleaning process, 150 duck eggs were put into a plastic basket, and the basket was put on a vibrostand (Shanghai Yihua Climate Simulation Equipment Co., ltd, Shanghai, China). Egg collision with each other under a vibration with low frequency and high amplitude during transportation was the main reason to cause egg shell damage. To simulate this kind of vibration, the vibration parameters were optimized by a trial test. A frequency of 5 Hz frequency and a vertical amplitude of 28 mm created by the vibrostand could make the duck eggs vibrated stable, and cracked without serious damage. After every 30 s of vibration, the eggs were checked manually using an LED light, and the duck egg with at least one crack was considered as a cracked duck egg. The cracked eggs were separated until 100 cracked duck eggs were collected. Next, 100 intact duck eggs were selected.

Samples of salted duck egg (before the steaming process) were collected from the salted duck egg process line of Gaoyou Red Sun Food Company, Jiangsu province, China. A total of 150 cracked salted duck eggs and 150 intact salted duck eggs were selected by experienced workers. After transportation to the laboratory, the salted duck egg samples were rechecked using an LED light, and finally, 149 cracked salted duck eggs and 140 intact salted duck eggs were obtained.

2.2. On-line egg translucent image capture system

In order to simulate the process line, an on-line egg translucent image capture system was set up. As shown in Fig. 1, the on-line egg translucent image capture system contained a single channel egg conveyor (Yangzhou Flourish Fruit and Vegetable Juice Machines Company, Jiangsu province, China), a high-speed CMOS color industrial camera (CM3-U3-13Y3C-CS, Point Grey Pesearch Inc. Made in Canada) with a camera lens (HS1214J, μTRON, MADE Japan), a self-made light source, a pair of optoelectronic switches, and a dark box. The speed of egg conveyor was set to 1 egg per second. The image capturing parameters of the high-speed CMOS industrial camera were set according to a focal length of 20 cm, a frame rate of 150 fps and a resolution of 1600×1200 pixels. The light source contained 3 LED lights, and the power of the single LED light was 1 W. As shown in Fig. 1B, when the eggs entered the dark box, the camera was triggered to capture the translucent image of the three eggs which were under the camera. As eggs were rolling through the dark box, three translucent images were obtained for every egg to make sure entire egg shell surface information could be captured while rolling.

2.3. Egg translucent image capture

The on-line egg translucent image capture system was used to capture the translucent images of the 200 samples of duck egg and the 289 samples of salted duck egg. Duck eggs were further divided into two categories according to the shell color, namely white shell duck eggs and green shell duck eggs. The green shell duck eggs had lower light transmittance compared to the white shell duck eggs. In order to avoid over-exposure or under-exposure of images corresponding to individual eggs, different gain values were used to capture the translucent images of white and green shell duck eggs. For white and green shell duck eggs, the gain value was set to 0 dB and 7.2 dB, respectively. After cropping, the size of the translucent image of a single egg was set to 440×628 pixels. As shown in Fig. 2, the translucent images of duck