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Crack detection on unwashed eggs using image processing

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ABSTRACT

A machine vision system for egg crack detection based on a modified pressure chamber and a continuously rotating egg was designed and implemented. The proposed system successfully collected surface images of the entire egg surface using only one pressure modification, which reduced the operation time and risk of enlarged cracks. In particular, this work focused on identifying cracks on unwashed eggs that were intact or cracked combined with being dirty. A robust crack detection algorithm was developed which optimized feature selection. The experiments were validated using 750 egg surface images with 94% accuracy and 1.67% false negatives.

1. Introduction

Egg production has been one of the fastest growing agricultural products over the past fifty years. The production volume increased by almost 52 million t during the period 1962 to 2012. The fastest growth of the egg production is in Asia. Asia contributes 39.2 million t or 59.0% of the global egg production. From 2010 to 2030, the global egg production will be increased by 35% and Asia will contribute to 64.8% of the total global growth (Windhorst, 2014).

Eggs are required to be washed in North America, Australia and some EU countries before they reach to the consumers; however, egg production process in all Asian countries except Japan involves unwashed eggs (Bichell, 2014; EUR-Lex, 2008; Lunadei et al., 2012). The washing process has an influence on shortening the lifetime of fresh eggs because of the potential damage to the physical barriers, such as the cuticle, which can occur during or after washing. For automatic egg crack detection system, unwashed egg surface poses more challenges since dirt on the eggshell interferes the system and cause misinterpretation of the system results.

Up to now, crack detection systems have been continuously developed by many researchers. The developed system mainly dedicated to identify cracks on washed eggs. Two most popular crack detection systems are vibration and machine vision analysis based systems. Vibration analysis measures frequency responses of an egg following repetitive, light mechanical impacts around the egg shell surface. For examples, De Ketelaere et al. (2000) reported that an intact egg has the same magnitude frequency response at different locations around the equator of the egg whereas a cracked egg shows a different magnitude frequency response at different locations on the equator of the egg. Jin et al. (2015) proposed to generate acoustic signals by rolling eggs on a seven-step plate to produce characteristic acoustic vectors. The system provided 90% accuracy with 10% false rejection.

The machine vision-based crack detection analyzes cracks on the egg shell using image processing or machine vision techniques. For example, Gooddrum and Elster (1992) proposed a machine vision system using a rotating egg and image processing. Three images were taken at 120° intervals around the egg equator. Adjusting the rotating speed of the system was used to accommodate different egg sizes. This system yields an accuracy of 94%, but De Ketelaere et al. (2004) found the speed of the crack detection system was slow. Omid et al. (2013) used a machine vision system and fuzzy logic to grade eggs into five categories being internal blood, spots, cracks, breakages and egg size. Their analysis reported an accuracy of 94.5% for crack detection and 98% for breakage detection.

Pan et al. (2011) proposed integrating the acoustic and computer vision techniques for crack detection since an accuracy of the acoustic response depends on environmental noises and uneven thickness in the eggshell. An accuracy of the computer vision

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system depends on the quality of image acquisition and the image processing algorithms. It has been claimed that vibration analysis is more accurate than a machine vision system. The vibration based system detects micro cracks which are hardly detectable by the human eye better than the vision based system. The proposed system use a back-propagation artificial neural network (BPANN). The obtained accuracy was 98%.

Efforts to develop a computer vision system to detect micro cracks were reported by Lawrence et al. (2008, 2009). The system utilized a modified pressure chamber and machine vision to detect micro cracks. The process involves the use of a short burst of vacuum to intensify the micro-crack in the eggshell surface. The micro crack is not visible at atmospheric pressure, but the crack is forced open and visible under vacuum pressure. To test the entire surface of the egg, at least three vacuum pulls are needed on a static egg. The system reported 99.6% accuracy with 0.3% false positives (Lawrence et al., 2009). Li et al. (2012) developed an algorithm to detect micro cracking in dirty eggshells using a modified pressure imaging system based on differences in the number of black pixels extracted from the egg images taken under atmospheric pressure and under vacuum conditions. The proposed method was reported as a promising crack detection system, but more advanced study was required for industrial application.

The systems reviewed above mainly focused on detecting cracks in washed eggs. To the best of our knowledge, no researcher has constructed a micro crack detection system on unwashed eggs. The objective of this research is to design a machine vision based crack detection system. The system focuses on detecting micro cracks in unwashed eggs. The proposed system acquires entire egg surfaces from the rotating egg using only one vacuum pull. In addition, feature selection is investigated and analyzed for egg crack detection algorithm.

2. Materials and methods

2.1. Egg samples

In this research, 50 white, unwashed, large-sized eggs were collected from local farms. Among all 50 sampled eggs, half were dirty—in this case due to soil, feces and/or feathers on the surface. All micro cracks were artificially inflicted by tapping gently on 30 eggshells. The unwashed eggs were classified into two groups being 30 cracked eggs and 20 intact eggs. For each egg, three images were collected thus the whole egg images in this experiments were 150 images. For use in system performance, hold-out validation was conducted by repeating 5 times and averaging the results (Refaeilzadeh et al., 2008). For each hold-out validation, all images were divided into two sets of 60% for training and 40% for testing without overlapping. As a result, 750 egg surface images consisting of 450 training images and 300 testing images were performed.

2.2. Machine vision system

The proposed machine vision system for detecting micro cracks on dirty egg shells consisted of two main modules, being one for acquisition and the other for image processing. The acquisition module captures images of egg surfaces under atmospheric (ATM) and vacuum (VAC) pressure. Under VAC condition, any existing crack will be revealed. This opening is extracted by the image processing module for crack analysis purposes.

2.2.1. Acquisition module

Typically, four vacuum pulls are used to capture the whole surface of an egg using the modified-pressure crack detection system. This study proposed to use only one vacuum pull for capturing the whole surface of an egg, resulting in reduced risks of surface egg enlargement. The pull reduction is accomplished by combining the continuously rotating egg technique with the modified-pressure imaging system. Rotating time synchronization is used to capture the whole egg surface within one vacuum pull. The proposed prototype system consists of a vacuum pump, a pressure tank, a testing chamber and a CCD camera, as shown in Fig. 1.

A vacuum pump (500 W) was used to generate the vacuum. The pressure tank was made of 5 mm thick steel with a diameter of 40 cm and a height of 40 cm. The testing chamber was connected to the tank to facilitate pressure adjustment inside the chamber. The test section had inside dimensions of 28 × 30 × 17 cm, the four sides of which were made of 6 mm thick steel while its top and bottom were made of 20 mm thick acrylic plates. To reduce the total cost of the proposed vision system, a small-sized vacuum pump was used in this research. However, the small size of the pump was unable to generate a sudden change of pressure inside the chamber, and so was unable to open cracks in the egg shell. Therefore, solenoid valve 1 (SV1), solenoid valve 2 (SV2) and the pressure tank were integrated between the pump and the testing chamber. By opening SV1, the pressure inside the tank slowly decreased to −330 mm. Hg. below atmospheric pressure, which was measured using pressure sensor 1 (PS1). By opening SV2, located between the pressure tank and testing chamber, the atmospheric pressure inside the chamber was abruptly reduced to the desired pressure of −254 mm. Hg. below atmospheric pressure. If an egg is cracked, this pressure can cause cracks to appear. In contrast, if the egg is intact, the egg can tolerate the change in pressure without any crack opening. Next, solenoid valve3 (SV3) was opened to regain atmospheric pressure inside the test section.

Inside the chamber, a small rotating single egg handle was constructed, as shown in Fig. 2. Two shafts were made of aluminum with a length of 13 cm. The shafts were used to mount a DC motor and four black rubber rollers. A computer coupled device (CCD) camera (iSight, Apple Inc., USA) with a resolution of 1280 × 720 pixels and a shutter speed of 240 frames per second was set up at a height (h) of 15 cm to acquire the images. By careful design, involving adjusting the speed of the rotating egg handle and the generated vacuum period, three images (A, B and C) were taken at 120° intervals around the egg equator as indicated in Fig. 3. The three images represent the entire egg surface.

In addition, it is important to provide a uniform light field on the egg surface, by sending light through the egg. With uniform lighting, a crack is more visible and easier to detect (DeKetelaere et al., 2000). To achieve this, a 50 W halogen light source was mounted under the chamber and two 1 W light-emitting diodes were mounted over the chamber.

2.2.2. Timing synchronization for acquiring VAC and ATM images'

In our system, three images under atmospheric pressure and another three images at vacuum pressure were considered as input images in the image processing analysis module. To acquire all six input images in one vacuum pull, the continuous rotating egg must synchronize its speed with the frame rate of the CCD camera and the timing interval of one vacuum period. In our study, the vacuum pressure condition (−254 mm. Hg.) lasted for 0.5 s and the ATM pressure lasted for about 0.5 s except for the first time of the operation.

In our system, the egg was rotated at a speed of 2 rps. Since eggs have different diameters, different rotating speeds were required. A tachometer was used to control the speed of the DC motor in order to maintain the speed of the rotating egg at 2 rps. The relationship of the frame rate of the camera, the speed of egg rotation and the pressure period is displayed in Fig. 4. Each image was captured at 40 frames interval.