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Araştırma Makalesi/*Research Article (Original Paper)*

Identification of Cracks in Eggs Shell Using Computer Vision and Hough Transform

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Abstract: Egg crack is one the main challenges that should be identified before sending it to market. In one hand, cracked eggs have strong potential in taking bacterial contamination and also they cause negative effects on the other intact eggs at packages so that this contamination endanger human's health. The objective of the current study was to propose a computerized method as an accurate, non- destructive and a fast method to identify the eggshell cracks. In order to detect the defects, the Hough transformation as a confident and qualified method with having the advantage of description based feature was used in determining the line in the images with assuming cracks as lines. The dataset consisted of 80 eggs which were included 45 healthy and 35 cracked eggs where taken images under controlled conditions. The cracks on the egg shells were identified by applying common preprocessing operations, a Canny edge detector and finally Hough transform. In the analysis section, the linear discriminant analysis was used to classify healthy samples from cracked ones. The results demonstrated satisfactory of the proposed approach in identification and classification of intact and cracked eggs so that we were able to reach 90.1% of accuracy in correct identification. The time for identifying the cracks in each egg was obtained 0.7 seconds.

Keywords: Classification, Computer vision, Crack, Eggs, Hough transform,

Yumurta Kabuğundaki Çatlakların Bilgisayar Görüntüsü ve Hough Dönüşümü Kullanılarak Tanımlanması

Öz: Yumurta çatlağı, pazara göndermeden önce tespit edilmesi gereken başlıca sorunlardan birisidir. Bir yandan, çatlamış yumurtalar yüksek oranda bakteriyel bulaşma potansiyeline sahiptir ve aynı zamanda paketlerdeki diğer sağlam yumurtalar üzerinde olumsuz etkilere neden olurlar, böylece bu bulaşma insan sağlığını tehlikeye sokabilir. Bu çalışmanın amacı, yumurta kabuğu çatlaklarını tanımlamak için bilgisayarlı bir yöntemi doğru, tahribatsız ve hızlı bir yöntem olarak önermektir. Kusurları saptamak için, çizgilerin çatlaklar olarak kabul edilmesiyle görüntülerde çizginin belirlenmesinde, tanımlama tabanlı özellik avantajına sahip, güvenilir ve kaliteli bir yöntem olarak Hough dönüşümü kullanılmıştır. Veri seti, görüntüleri kontrollü koşullarda çekilen 45 sağlıklı ve 35 kırık yumurtada içeren 80 adet yumurtadan oluşmaktadır. Yumurta kabuklarındaki çatlaklar, Canny kenar detektörü ve son olarak Hough dönüşümü içeren ortak ön işleme işlemleri uygulanarak belirlenmiştir. Analiz bölümünde, sağlıklı örnekleri kırık olanlardan sınıflandırmak için doğrusal diskriminant analizi kullanılmıştır. Sonuçlar, sağlam ve çatlamış yumurtaların tanımlanmasında ve sınıflandırılmasında önerilen yaklaşımın tatmin edici olduğunu göstermiş; böylece doğru tanımlamada doğruluk oranının % 90.1'ine ulaşabilmiştir. Her bir yumurtanın çatlaklarını belirleme zamanı, 0.7 saniye olmuştur.

Anahtar kelimeler: Sınıflandırma, Bilgisayarlı görüntüsü, Çatlak, Yumurta, Hough dönüşümü,

Introduction

Eggs are one of the most common and most used foods in the food basket of people. It is a good source of protein, vitamins, and essential minerals, and can be used as an important food in people diet.

In response to the demand of food industry professionals and also consumers, the use of advanced methods in the classification of eggs is necessary. The developed machines are able to grade 120 000 eggs in one hour (Lawrence et al. 2008). These various apparatus are used in egg processing and analyzing from one hand and development of technology of grading in parallel on the other hand have lead new industrial machines to play an important role in processing of eggs and categorizing them according quality (Li et al. 2012). Qualitative parameters such as degree of freshness; cleanliness of eggshell (without contamination and blood spots); the internal quality of the egg, including the presence of blood in the yolk, the growth of the fetus, and finally the cracks in the eggshell are very important factors that are measured in the production line and packaging centers.

Detecting egg cracks is one of the issues facing producer, food industry experts and, ultimately, consumers because they can be the origin of disease transmission. Additionally, some cracks on the eggshell are very small and cannot be detected by visual inspection by humans. Therefore, detecting cracks on egg shell has extra importance as it is related to the people's health directly. Hence, developing an appropriate method for monitoring of all eggs that lacks disadvantages of low accuracy, slowness and destructiveness is needed. To overcome the above challenge, computer vision and image analysis can be helpful, so that the cracks can be detected accurately without damage to the eggs during the detection process.

In the country, few studies have been carried out to detect egg cracks. However, there are several studies in the rest of the world. Aghkhani and Pourreza (2007) performed a study on egg grading using a machine vision system. Their aim was to determine the mass, volume and also contamination of eggshell. According to their report, the determination of mottled eggs was done by comparing their histogram with healthy and clean eggs with 100% accuracy. Mass and volume were calculated with less than 1% error. They also suggested a higher processing speed for more practical applications. Dactlayer et al. (2004) reported that, in general, egg cracks detection methods are divided into three categories: mechanical, vibration analysis, and computer vision. In the mechanical method, usually, a small hammer is used to create turbulence on the egg surface. Hammer is essentially an electromagnetic probe that is stimulated by the induction of its electromagnetic coil and hits the egg surface located between two mechanical rollers. In the next step, cracked eggs are identified by comparing the amplitude of the response to the strike, as well as counting the number of backward movement of the probe and comparing them with healthy samples that were previously recorded. In some cases, instead of electromagnetic stimulation, the sensors of the piezoelectric are used, which has the same function. The effect of the strike is checked between 24 and 32 points. The accuracy of this method is relatively acceptable (about 90%). Also, estimating the strength of eggshells is one of the advantages of this method, but the probability of cracking during strikes to egg and the time-consuming process of the crack detection, are the disadvantages of mechanical methods. In vibrational methods, which are partly similar to mechanical methods, a laser vibrometer is usually used to record vibrations caused by a strike of a hammer equipped with a dynamometer. If the amplitude of vibration does not reach a certain threshold, an amplifier will be used.

The vibration generated in all three dimensions of the coordinate axes (x, y, and, z) are analyzed in order to accurately analyze and achieve to the desired accuracy in identifying defects of egg shells. Finally, by analyzing the vibration frequency in different modes for both healthy and cracked eggs, and considering the resonance frequency of egg in the corresponding relations, defective samples are identified. The accuracy of above 90% and also the ability to determine the thickness of eggshell is one of the advantages of this method. The time consuming and the need for relatively expensive laboratory facilities are the disadvantages of vibrational techniques.

Computer vision-based approaches are another set of new approaches to inspection, monitoring and quality measurement of productions in various industries, especially food industry. With increasing processing power, the amount of memory, and digitalization of electronic devices like imaging cameras, high efficiency can be expected in utilizing this technology. The most important positive indicator of computer vision is its non-destructiveness so that determination and isolation of food products without the least damage is a desirable goal for most people involved in this field. Regarding the detection of cracks in the eggshell by providing digital images and processing them in the computer environment, in addition to non- destructiveness, the benefits such as accuracy, speed, and reliability can be achieved. In Table 1, three approaches consist of mechanical, vibration analysis, and computer vision in identification food defects have been compared.

Table 1. Comparison of three methods of defect detection in food products.

Method	Accuracy	Speed	Destructiveness	Reliability
Mechanical	80-90%	Slow	Destructive	Low
Vibrational	More than 90%	Slow	Destructive	Relatively high
Computer vision	More than 90%	Fast	Non- destructive	High

According to Chu et al. (2000), most non-destructive crack detection methods are based on the analysis of sound features and computer vision (Chu et al. 2000). Li et al. (2012) detected and identified cracked eggs by analyzing the sound signals caused by the strike to eggshells. They were able to reach 95% accuracy by calculating the energy of these signals using the wavelet transform method and comparing the values obtained for healthy and unhealthy eggs. A similar study was conducted by Jane et al. (2015) using the method of audio frequency response analysis. Zhao et al. (2010) also studied the detection of the eggshell cracks by analyzing the dynamic frequency response. They measured the resonance frequency for both healthy and cracked eggs by applying gentle mechanical gentle pressure to different parts of the eggs and using a thin and flexible piezoelectric sensor and separated the cracked eggs using a linear discriminant analysis with 10 frequency characteristics.

Image processing and machine vision are another methods used by researchers to identify the cracks. Lawrence et al. (2008) developed a machine vision system equipped with a pressure chamber to find the location of the crack on the eggshell. They made a small chamber to create the vacuum and force needed to split the cracks on the eggshell. According to their report, all 80 cracked eggs among 80 healthy eggs were correctly identified. Vertens et al. (2011) examined advanced methods for controlling egg quality. Two of these methods refer to the use of spectroscopy in determining the quality of the inner and outer surfaces of eggs, Also they pointed to the capability of machine vision technology especially multi-spectrum imaging in the quality evaluation of the common defects in this product. Nashat et al. (2014) identified and isolated cracked biscuits using image analysis and implementing of Hough transform method. Their goal was to overcome the challenge of inspecting and controlling cracked biscuits that had a non-uniform colour distribution. In their study, a pyramidal process was used to extract the characteristic from biscuit images and cracks were identified by the Hough transform method and support vector machine. According their report the accuracy of this method was more than 97% and was highly desirable. Priyadmukol et al. (2017) investigated the effect of dirtiness and the cleaning of eggs by washing for identifying of micro-cracks by image processing. The results showed that the clean shell of egg samples had a significant effect on the detection of defective samples so that they ultimately reached 94% of separation accuracy.

Materials and Methods

Hough transform

Hough transform is a feature extraction tool used in image analysis, machine vision, and image processing. In some texts, Hough transform is called to as a magic method. Because it allows user to identify not only lines but also other shapes in the image. Hough transform can be used to determine the slope and the intersection of lines. Since a line is composed of a set of points and managing a set of points is more difficult than managing a single point, so the most important issue is to find a way to show a single point without losing all data of the line.

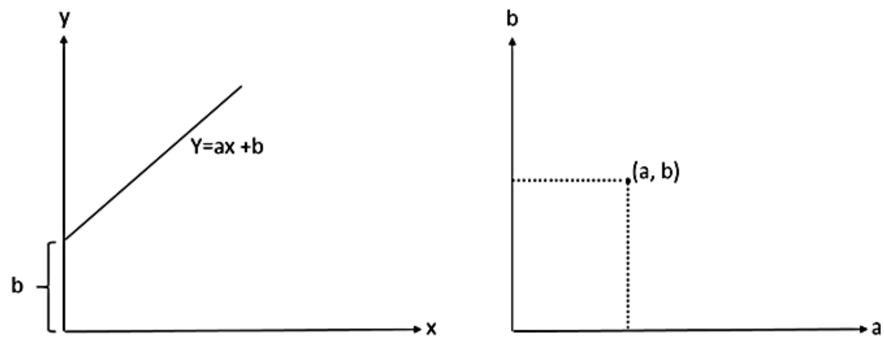

Figure 1. Transformation of a line from xy space to feature space

By considering a given line in an image, for each non-zero point on this line, the corresponding lines can be plotted in the ab space. In this case, the probability that some lines will cut each other is very high. The location of these intersections gives the parameters of the line shown in xy space. This is the idea behind the Hough transform.

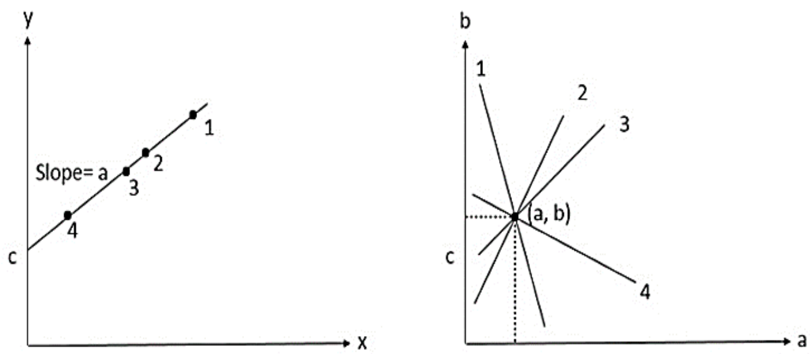

Figure 2. Transformation of multiple points in xy space to several lines in the parameter space

This view shows that if the slope of the line is infinite (a perpendicular line), the use of this transform is not feasible. This is one of the major failures of the Hough transform.

The above problem can be resolved by applying a method in determining the line parameters. Such that, instead of writing the general equation of the line in the Cartesian coordinates (If the line is perpendicular, its slope tends to infinity.), use the normal form of the line in which instead of the two of slope and vertical intercept parameters, use ρ and θ, both of which are finite (Fig.3).

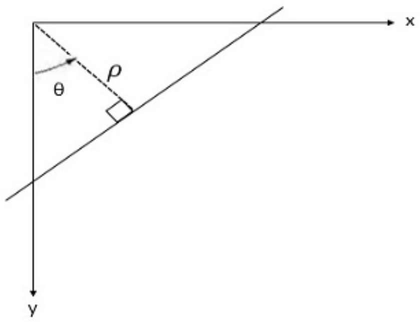

Figure 3. Normal form of line in the xy space

Due to the nature of the image in MATLAB software, the graph in Cartesian coordinates is depicted as above. In this figure, the maximum angle is θ=180° (between -90° and 90°) and the maximum value of ρ is from zero to the diameter of the image. In any case, the equation of the above line in the figure will be as follows:

$$x\cos\theta + y\sin\theta = \rho \qquad (1)$$

In this new relation, a line in the Cartesian coordinates is also equal to a point in the feature coordinates, but a point in the Cartesian coordinates is equal to a sinusoidal curve in the characteristic coordinates ($\rho\theta$). All pixels in the image under the Hough transform are scored, and the intersections resulting from the intersection of the sinusoidal curves in the $\rho\theta$ space are examined, and each point that has a higher score (brighter points) will have a higher probability of having a line. It should be noted that the Hough transform works on the edge images, which can have several reasons. Firstly, working on color images is of order n to power three, which is very time-consuming. Secondly, we are not only looking to find a line in the image, because an edge detector algorithm such as Canny and Prewitt also does the same thing. Therefore, describing the line and obtaining more information, such as determining the longest ones, or determining the line equation, is also part of our goals. In the present study, egg cracks play a role of a line. As mentioned in the introduction section, pixels on the cracked region are scored by the Hough transform, and in the space of this transform (θ, ρ), each brighter point represents a line (crack on the eggshell). The location of the crack along with its length can be determined by Hough transform. Although Hough transform is usually used to find the straight lines in the image, by applying changes, it can also be used to identify other shapes like the circle. In other words, the use of Hough transform is not limited to extracting the properties of straight lines. Comparison among images is another application of Hough transform because Hough transform is robust to the scaling and images size.

Circular Hough transform

Hough transform also can be applied on any function in the form of $g(V, C) = 0$ where V is a vector of coordinates and C are coefficients. For instance, the points on the following circle can be find with the mentioned method.

$$(x - c_1)^2 + (y - c_2)^2 = c_3^2 \qquad (2)$$

The only difference is parameter triplets (c_1, c_2, c_3) that leads to parameter space with cubic cells. Each point in geometric space generates a circle in parameter space so that circle in a parameter space can be described by the following formula:

$$\begin{cases} x = c_1 + c_3\cos(\theta) \\ y = c_2 + c_3\sin(\theta) \end{cases} \qquad (3)$$

Imaging system

Figure 4 shows a dome-shaped imaging compartment which is used to capture images of egg samples. The chamber is designed in such a way that external light sources do not enter. There are four rows of LED light and four fluorescent lamps with the same distance inside the compartment. Light sources are placed at an angle of 45 degrees to the object. The 12V fixed voltage fed the lighting system. A hole is mounted on top of the compartment where the camera lens is positioned inside and covered completely to prevent any light source from entering the inside of it except for light sources of chamber. The camera used in this study was a CCD camera (SONY α 200) with a resolution of 10.1 megapixels, 40mm lens, and lens opening f 5.6. The backgrounds used to put potatoes on it were black Steinbach's paper. The main advantage of this paper is the lack of reflection of light. In addition, the black background creates conditions for the desired contrast due to the whiteness of the eggs. So that, as soon as the sample is placed in front of the camera lens, focusing is done on the object and the image with good quality and without blurring is captured. The distance of the camera lens to samples surface was adjusted to 29 cm. Cracks on the egg surface were placed in front of the camera lens and then after being stable, the digital image was taken. The number of healthy eggs was 45 and the number of cracked eggs was 35.

Figure 4. Imaging compartment computer vision system

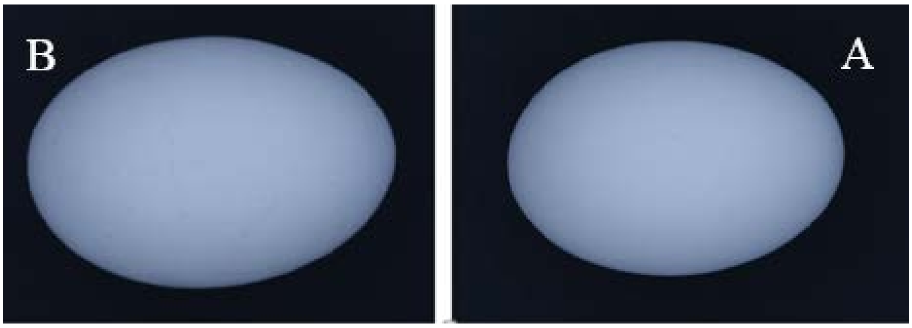

Figure 5. Sample image of two eggs. (A) Healthy eggs; and (B) cracked eggs

System software

All software operations were performed on 64-bit Lenovo computer system with a 1.9 GHz Core i3 CPU and 4 GB RAM. Processes including pre-processing, edge detection, and other processes, were performed by the MATLAB R2017a software package, which is shown as a flowchart in Figure 6. The pre-processing in this study included reducing image size, de-noising, and removing the background from the image, an example of which is given in Figure 7.

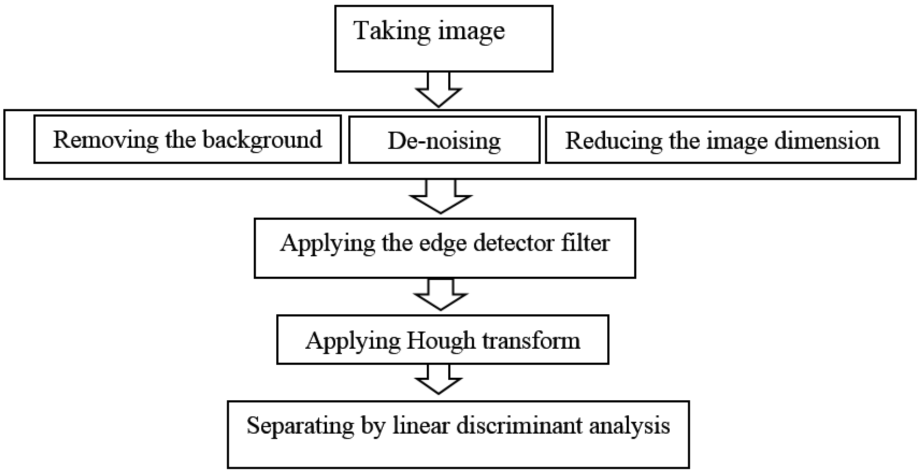

Figure 6. Cracked egg detection flowchart

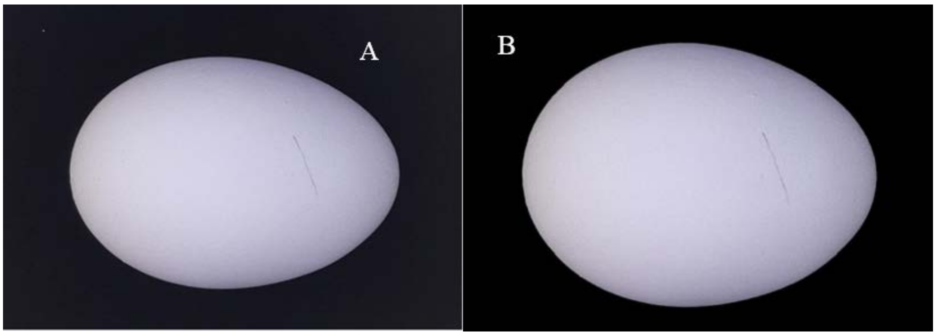

Figure 7. A) Original image B) Pre-processed image

Edge detection

Before applying Hough transform for determining the crack location, the position of cracks on the egg samples should be determined relatively. Since the cracks are places where the intensity of the lighting changes suddenly, so they can be considered as an edge. Therefore, an edge detector filter called Canny was used for this purpose. In other words, the Hough transform looking for crack where the edge is likely to be there. In addition to improving the accuracy of action, it is also a kind of reduction in the size of the search space for converting Hough transform to converge quickly to the answer. Using canny edge detector provides a better visual representation of the fracture and cracks places. Figure 8 shows the result of applying this filter on an image.

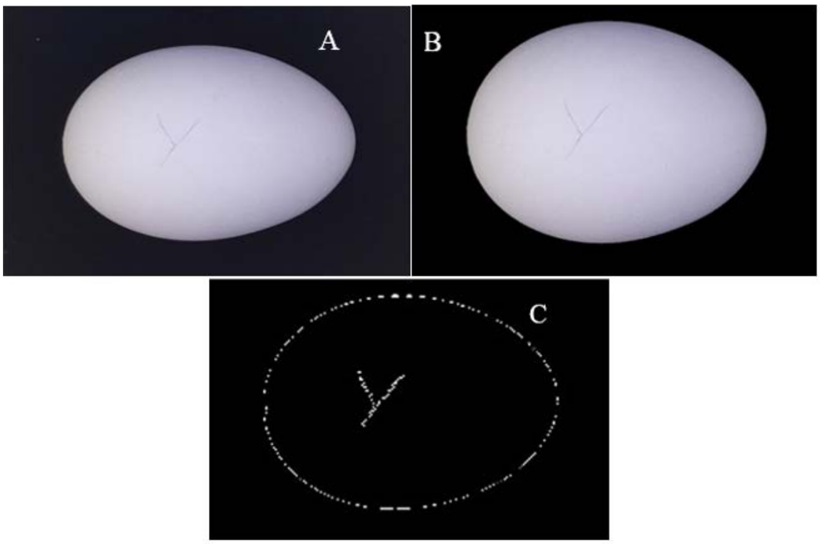

Figure 8. A) Original image, B) Pre-processed image, and C) The result of applying the canny filter and determining the crack location

Implementation of the Hough transform

After obtaining the edge map of the egg images, the Hough transform is applied. With the help of this map, the points that sinusoidal curves are crossed and the line is likely to exist is reduced, thus the time to find possible lines is reduced, which is a plus point for us. The angle at which the interval of points is scored is set to 180 degrees. To match the number of lines found with real cracks on the egg surface, two conditions were handled. The first one is that lines with a length less than a certain value (4 pixels) are not considered as lines. Secondly, it merges the points on a line that is lower than the optimal threshold (in this study with a try and error was considered 15 pixels). These two conditions were very effective in identifying cracks. In addition to these two cases, from the first, the number of examined lines was considered 10 lines limitedly. This means that in each egg samples the Hough transform does not identify more than 10 cracks. In the image of the Hough transform that is a parametric space, pixels that were brighter than others (with a brightness close to 255) were more likely to have a crack on the eggshell. Also, in real time applications the kernel- based Hough transform technique can be used that is more robust to noise and missing data. We aim at use it in the future work.

Results and Discussion

In this study, after taking an image of some healthy and cracked eggs and applying pre-processing, including de-noising and image binarization, Hough transform method was used to identify cracks on the eggshells. Figure 9 shows an example of the correct diagnosis of Hough transform in the detection of egg crack. In this figure, the left image is the parametric space $\rho\theta$ so that this image contains all pixels obtained from the canny filter that have the probability of line existence in it.

The pixels of the image that are brighter are more suspected to have cracks. Therefore, the brightest parts of this parametric space confirm the presence of the cracks. According to this figure, only one point is brighter than others, and as is shown, it is the place of the crack which is correctly identified. In some cases the eggs that had a dirty surface with animal excreta and other things, in some cases, the proposed algorithm fails to recognize the crack. If this contamination was in the form of a thin line on the egg surface, the Hough transform method was mistakenly considered as a crack. These things happen a little because most of the spots don't similar to shape of a line, and appear as a small area at the egg surface. An example of this is shown in Figure 10. The necessary time from the beginning of the image uploaded in the MATLAB software environment until the moment of detecting the crack on the samples was approximately obtained 0.7 seconds per each egg sample, which is acceptable at a small scale.

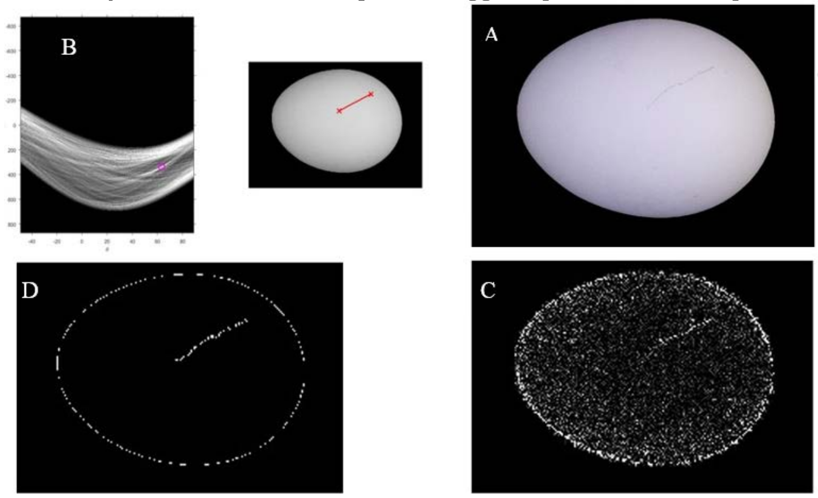

Figure 9. An example of a crack detection using the Hough transform method. A) Original image; B) Identifying the crack location; C) Canny edge detector filter, and D) Modified result of the Canny filter

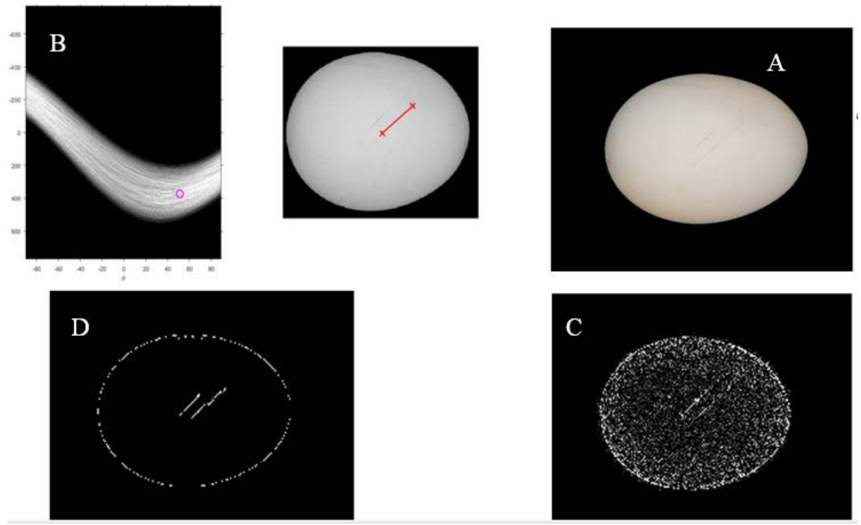

Figure 10. Incorrect spot detection instead of real crack. A) Original image; B) Incorrect crack identifying; C) Canny edge finder detector; and D) Modified result of the Canny filter

The results of classification of healthy and faulty eggs has been listed in table 2. The Discriminant Analysis method as a linear classifier is separated intact samples from cracked ones.

Table 2. Results of discriminant analysis classification.

Predicted group membership (number)			
Egg type			Total
	Healthy	Cracked	
Intact	40	5	45
Cracked	3	32	35

According to the table, of 45 healthy eggs, 40 eggs were correctly classified in their own class and 5 eggs were wrongly classified as unhealthy eggs. However, of 35 cracked eggs, 32 eggs were correctly detected and 3 eggs were placed in the healthy group.

According to the values of Table 3, the accuracy of cracked eggs detection among all 80 samples (healthy and non-healthy) was 90.1%. Given the fact that no changes were made to the mottled eggs before the image was taken, this amount of accuracy in identification and classification was desirable.

In the cases that intact eggs were determined instead of damaged ones or incorrect identification of the crack location is refer to the presence of contamination on eggs. The dirty spot, including poultry feces or anything else, caused a fault in the detection of cracks, especially spots that were appeared randomly in the form of a narrow line on the eggshell. To overcome this problem, it is suggested that before taking the image of the eggs, it is better that rinse them out by water, then the imaging is done, otherwise relatively complex algorithms are needed to identify the actual cracks on the dirty eggs.

Table 3: Accuracy classification of Discriminant Analysis

The accuracy of predicted group (%)			
Eggs type			Total
	Healthy	Cracked	
Healthy	88.8	11.2	100
Cracked	8.6	91.4	100

Conclusion

This study uses a computer vision-based approach to detect the most common defects appeared in eggs (cracks and fractures). Aside from the proper speed and accuracy, the non-destructiveness proposed method is the most important motivation and the reason for its use in the present research. Among the algorithms used to identify the line in the image, we used the Hough transform method, considering the crack shape formed on the egg surface as a line. The reason for the superiority of Hough transform to other detectors such as edge detector and corner detectors algorithms, is the descriptive approach of this method with a single line, so that it is possible to determine the line as a parametric form and determine the largest and also the smallest line (crack in our study). Our proposed method for crack detection with an average accuracy of 90.1% was able to separate cracked eggs from healthy samples. When implementing this method, some parameters were manually initialized, which could be considered as a disadvantage of the proposed method. If it is possible to determine their values by a more advanced method, such as optimal search through genetic algorithms and other nature- inspired algorithms, it will be very useful. For the next step, it is suggested that at least two cameras should be used at the top and bottom of the egg to take a digital image of them when moving in front of the camera lens. Having more images allows to monitor the entire surface of the eggshell and can be easily used in industrial pilots. In this case, the only remaining problem is to reduce the processing time and crack detection process due to the presence of more than one image. This can be solved by optimizing the implementation of the Hough transform, including the adaptive treatment (not the general) with parameters of this transform.

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