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An expert egg grading system based on machine vision and artificial intelligence techniques

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ABSTRACT

The main purpose of this research was design and development of an intelligent system based on combined fuzzy logic and machine vision techniques for grading of egg using parameters such as defects and size of eggs. The detected defects were internal blood spots, cracks and breakages of eggshell. The Hue-Saturation-Value (HSV) color space was found useful in obtaining visual features during Image Processing (IP) stage. The fuzzy inference system (FIS) was designed based on triangular and trapezoidal membership functions, fuzzy rules with logical operator of AND inference system of Mamdani and method of center average for defuzzifier. The evaluation results of IP algorithms showed that use of IP technique has good performance for defects and size detection. The Correct Classification rate (CCR) was 95% for size detection, 94.5% for crack detection and 98% for breakage detection. The overall accuracy FIS model in grading of the eggs was 95.4.

1. Introduction

Egg is an inexpensive but very nutritious component within the human diet. Egg is one of the most important poultry products because it has a large amount of protein, vitamins and omega 3. It is one of the few foods that are used widely worldwide and are healthy and safe for consumers. Egg is a vehicle for reproduction and can be raw material for many products in food processing plants. Defect determination and grading of egg is the main operation that a human operator cannot able to work perfectly and continuously because of eye fatigue and increasing error due to over wearing. Many scientists and researchers attempted to design and develop an automatic system for egg grading.

Garcia-Alegre et al. (1998) introduced a machine vision system to detect egg defects. They used a digital camera with three CCD sensors, 752 $\times$ 582 pixel with rate of 30 frames per second. The main problems in this research were low differences in intensity and color between defects, background, and the emergence of a bright spot in the center of the eggshells. They reported that from regular samples of eggs 82% were classified correctly and 18% were rejected as defective eggs. But from defective specimens, 92% were correctly graded and 8% were misclassified. Patel et al. (1998) developed a computer vision system to sort defective eggs from intact ones. The developed system was composed of a CCD camera, image processing board, egg candling lamp, personal computer and a monitor. The distance of camera lens from samples was set on 555 mm. They utilized color images of eggs, and red, green and blue (RGB) histograms were extracted from images. They reported the developed neural network model for blood spot detection, dirt stained eggs and crack detection had 92.8%, 85% and 87.8% accuracy, respectively. The average accuracy of the neural network was reported 87.8%. They concluded these accuracy levels were sufficient to produce graded samples that would exceed the USDA (Anonymous, 2000) requirements. Nakano et al. (1998) developed machine vision technique for detection of blood spot in egg. They injected blood into intact samples and made bloody eggs artificially. Acquired images were stored in a personal computer and were analyzed. For white eggs, the RGB components of images were applied in assessment of defective samples. For green component and to separate bloody eggs from intact samples, the threshold was set at 0.29. The detection accuracy for bloody and intact eggs was obtained 96.2% and 92.5%, respectively. This method did not obtain satisfying result for detection of blood spots in brown eggs.

Dehrouyeh et al. (2010) developed a system based on image processing for detecting internal blood spots and eggshell dirt by processing acquired images from egg samples. They used hue histogram for blood spots detection, and maximum values of two ends of histogram were also selected as criterions of defect detection. Eggshell dirt was detected using connected areas detection technique. They reported that accuracy of differentiation of blood spots algorithm was 90.66% of defected eggs and 91.33% of intact eggs and total average of this algorithm was 91%. Accuracy of dif-

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ferentiation of dirt detect algorithm was 86% of clean eggs, 83% of low dirt eggs and 88% of high dirt eggs.

Other researches were conducted recently in this area by Mertens et al. (2005), Pan et al. (2011) and Li et al. (2012).

Acoustic impulse technique has also been used to detect cracks in eggshells. In this method, a pendulum strikes the egg and an acoustic signal is produced. The produced signal is received by a microphone and after amplification and conditioning it is transferred to a computer for digital signal processing. The raw signal is analyzed and its characteristics are extracted. Then a regression models or neural network correlates between egg quality indices and acoustic signal attributes (Cho et al., 2000). Jindal and Sritham (2003) and Wang and Jiang (2004) also researched in this field and reported their findings.

Usui et al. (2003) applied near infrared spectroscopy to detect blood spots in egg. Since blood in egg includes hemoglobin particles, so the absorbance band of infrared spectrum differs from intact ones. They used partial least squares (PLS) regression analysis with a wavelength range of 503–598 nm as an explanatory variable. They reported that normal eggs discrimination rate was 100%, and eggs with blood spot discrimination rate was 83.0%. When predictions were made for unexamined specimens, the discrimination rate for normal eggs was 100%, and that for eggs with blood spots was 96.8%.

This study aims to design and evaluate an expert system in order to grade white egg based on defects and size, using machine vision technique, fuzzy logic inference (FIS) and Simulink tools. The studied defects were include internal blood spots, crack, breakage (or hole) and dirt stain. The mentioned defects with size of egg were fed to the expert system classifier as inputs and based on FIS, the egg samples were graded.

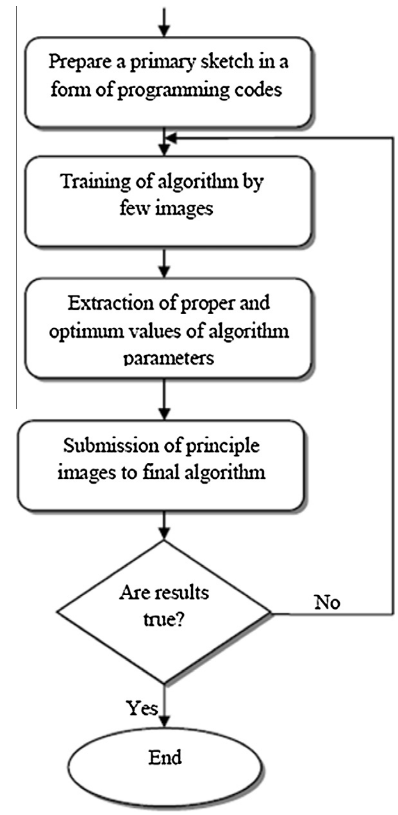

Fig. 1. Steps of image processing algorithm design.

2. Materials and methods

In this research, white eggs in different sizes were collected from local hatchery and brought to the laboratory for analysis. Intact as well as naturally defected eggs were collected from a hatchery. Among the sample eggs some of them had blood spots, some had cracks and others had breakage.

2.1. Machine vision system

To have a proper image of an egg, creation of a uniform light around the sample is important and must be carefully designed. Accordingly, to have a suitable illumination and to eliminate effects of environmental noises a cubic box of $0.40 \times 0.40 \times 0.40$ m was fabricated. For crack, breakage and blood spot detection primary experiments indicated that illumination from below (candling) yielded better results than direct illumination from top. A 50 W halogen lamp was therefore installed at the bottom of box. A SAMSUNG™ CCD camera (model: SDN-550) was used and fixed approximately 200 mm above the egg sample. The camera had 768×576 pixels in horizontal and vertical directions, respectively and its resolution was 530 TV lines. The camera was attached to a personal computer (PC) through a WINFAST™ frame grabber.

2.2. Image processing

Fig. 1 shows the steps of design of image processing algorithm in this research. In most machine vision system, the procedure of design algorithm is elimination of unnecessary information or carrying out preprocessing (Mc Andrew, 2004). To achieve this purpose, captured images must be segmented. In segmentation process, image is divided in parts that made it. The region of interest is remained and others are eliminated from processing procedure. Segmentation in this research mainly specified to separate egg from background. So region of interest is the surface of eggshell and other parts were removed. In next step, the developed algorithm should be able to differentiate among intact and defective eggs by means of extracted components of each sample. The MATLAB 7.6 software was used for image processing, expert system design and simulation.

2.2.1. Preprocessing

The acquired image was sent to MATLAB and converted into two-dimensional matrix for further analysis. The dimensions of image using *imresize* function resized to a 256×256 matrix. Selection of 256 (2^8) was through bit structure of image pixels that simplified processing operations. By variation of image dimensions, the shape of egg is also varies. In all processes, classification of each egg was made, not as a discrete sample, but as a sample in comparison with other eggs, was inspected. Because of this comparative view in grading process and similar variation in all images, no problem was occurred in recognition of attributes because of image dimensions variation. Fig. 2 shows a typical egg image before and after resizing.

The HSV (Hue, Saturation and Value) color space was used in image processing. Initially, using *rgb2hsv* code, the RGB images were converted to HSV ones (Fig. 3).

2.2.2. Segmentation

The purpose of segmentation is division of image into its composed parts. This operation was performed to eliminate the background and simplify next processing on image. The output in this step was a color image that included only the picture of egg.

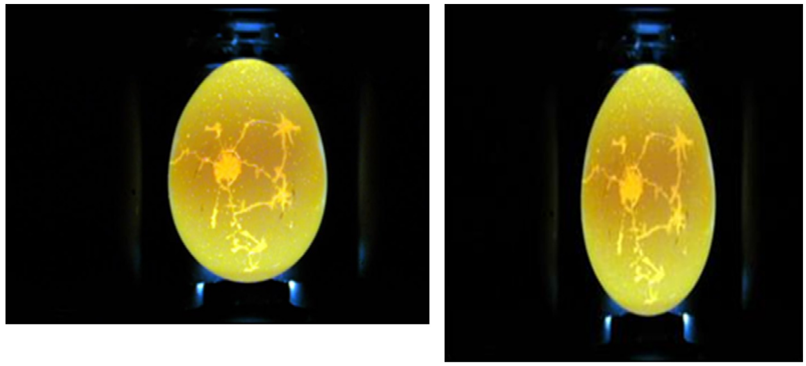

Fig. 2. The original and resized picture of egg.

2.2.3. Egg size determination

The size of egg is one of the most important parameters in egg classification. To determine egg size the following method was used: After segmentation, the red color plan of RGB image was separated and new image was formed. Undesirable stains (due to dirt, breakage and cracks) affected the pixel numbering and caused a high error in size determination. In order to eliminate these areas, the *imfill* function was used for this purpose. The algorithm of this function operates based on morphological reconstruction on binary images (Gonzalez et al., 2004). Finally, the number of nonzero pixels of eggshell was counted and by a sufficient correlation between pixel number and size of egg, the size was obtained.

2.2.4. Defects determination

In this research, crack, breakage and blood spot were all determined and used as defects for egg grading. After segmentation, the image was converted into gray scale and the edge of egg with threshold value of 0.14 was used to determine the cracks in eggs. No difference was observed between pixels of cracks edge and egg shell edge. Therefore the eggshell edge was recognized and removed form image using Laplacian of a Gaussian (LoG) method and fixing the threshold on 0.015. After crack identification, the pixels of crack were counted. In order to have a unit indicator for all defective samples the following formula was used to calculates the crack percent:

$$\%\,\text{Crack} = \frac{\text{number of crack pixels}}{\text{number of egg surface pixels}} \times 100 \qquad (1)$$

When a part of egg is broken, more beams of light can pass from broken part. The RGB image was used and a threshold value was found for each of red, green and blue color planes separately and thresholds were correlated together with *AND* operator (Fig. 4). Additional information about blood spot recognition was described by Dehrouyeh et al. (2010).

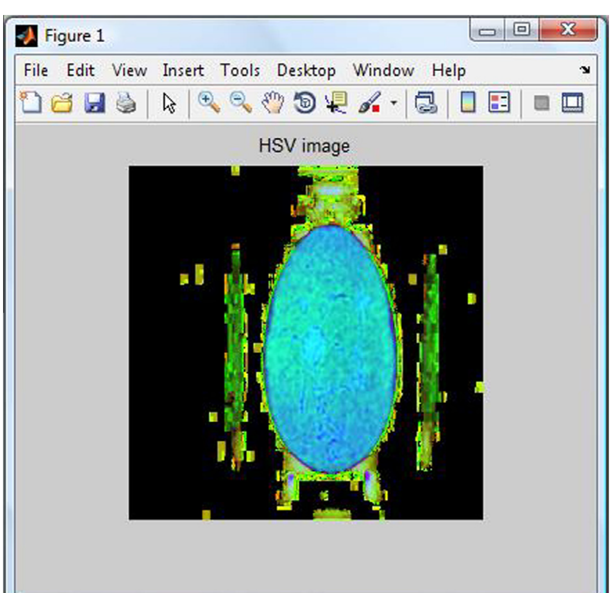

Fig. 3. The HSV image of a typical sample.

2.3. Fuzzy system classifier

The fuzzy inference system (FIS) was designed in four parts including selection of input and output membership functions (MFs), fuzzy rule base, fuzzy inference engine and defuzzifier. The output of designed classification system is egg's grade. Triangular MFs were used for the output of FIS. The expert system graded egg in five classes by experts, Excellent (A), Good (B), Medium (C), Bad (D) and Wastage (E).

Selection input variables and their MFs have important role in the design of FIS. For egg classification, the parameters must be selected that have a noticeable influence in quality control and acceptability. Based on this view, defects and size of egg were determined as inputs. Four variables (crack, blood spot, breakage (hole) and size) were defined as inputs of fuzzy system. Blood spot and breakage are crisp variables that classify the egg in wastage class. For eggshell crack, four fuzzy sets, No crack (NC), Low crack (LC), Medium crack (MC) and High crack (HC) were defined and for size, three sets, Small, Medium and Large were specified.

Three types of fuzzifiers, namely, triangular, S-shaped and Z-shaped were used. Figs. 5–7 show the fuzzifiers. Blood spots and eggshell breakage are the crisp variables and therefore we only need to set a threshold value for them.

2.3.1. Rule base

Rule base is a set of IF–THEN rules that makes a relation between input membership values and outputs. The number of fuzzy rules is obtained by multiplying of the input sets ($4 \times 3 \times 2 \times 2 = 45$). Making decision about egg, if the sample is bloody or broken, is sufficient to classify it in wastage class (as these to variables are crisp). In this case, the other variables have not any influence in decision procedure. So the fuzzy rules number decreased to 14. The rules are presented in Table 1.

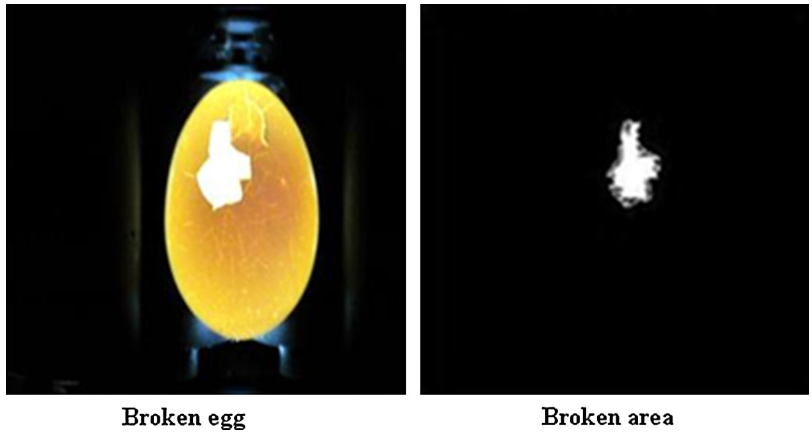

Fig. 4. A typical broken egg and broken area recognition.

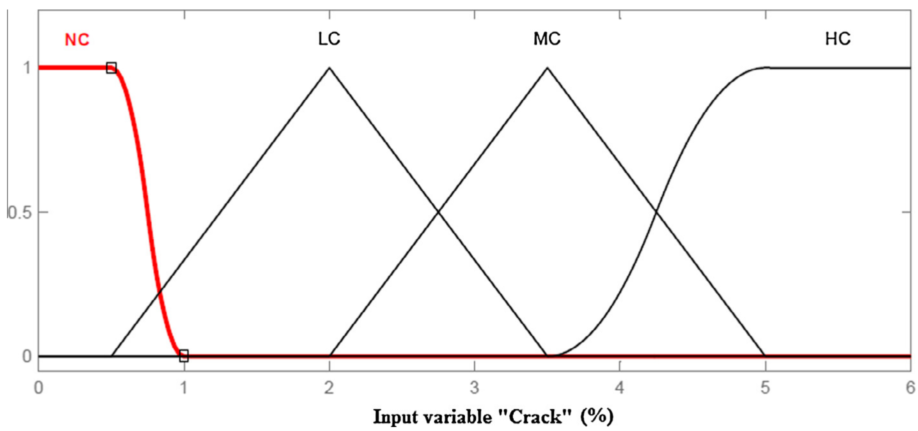

Fig. 5. Fuzzifier of egg shell crack sets.

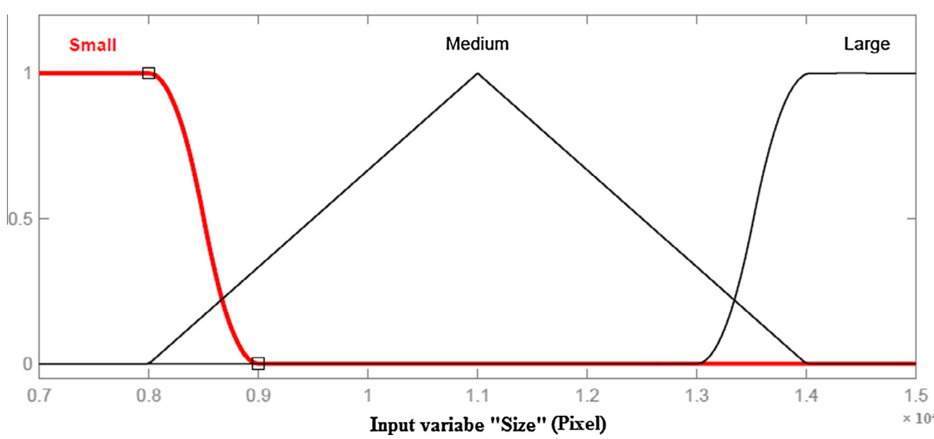

Fig. 6. Egg size fuzzifier.

2.3.2. Fuzzy inference engine

The Mamdani inference engine was used in this research. This inference engine uses *min* operator as a fuzzy implication operator and maxs-min operator for the composition (Moser and Navara, 2002; Lee, 2005).

2.3.3. Defuzzifier

Defuzzification is a method to specify a crisp value for output that is obtained from fuzzy rule composition. Here the center of average defuzzification was used from the MATLAB's FIS libraries (MathWorks, 2007).

2.4. Algorithm evaluation

Extraction of knowledge from human experts was the next step after algorithm design. Expert's judgment (opinion) was used in two ways: for fuzzy interval determination and algorithm evaluation. In the first case, the expert's judgment was used for determi-

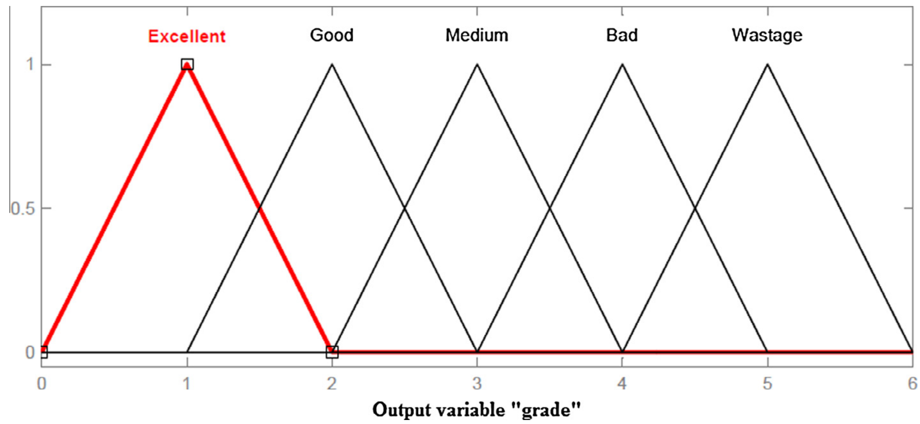

Fig. 7. The triangular fuzzy sets for output.

Table 1
Fuzzy rules in expert system of egg classification.

1	IF Egg is (not Bloody) AND (not Broken) AND (No Crack) AND (Large) THEN (Grade is A)
2	IF Egg is (not Bloody) AND (Breakage is not Broken) AND (Crack is No Crack) AND (Size is Medium) THEN (Grade is B)
3	IF Egg is (not Bloody) AND (Breakage is not Broken) AND (Crack is No Crack) AND (Size is Small) THEN (Grade is B)
4	IF Egg is (not Bloody) AND (Breakage is not Broken) AND (Crack is Low Crack) AND (Size is Large) THEN (Grade is B)
5	IF Egg is (not Bloody) AND (Breakage is not Broken) AND (Crack is Low Crack) AND (Size is Medium) THEN (Grade is C)
6	IF Egg is (not Bloody) AND (Breakage is not Broken) AND (Crack is Low Crack) AND (Size is Small) THEN (Grade is C)
7	IF Egg is (not Bloody) AND (Breakage is not Broken) AND (Crack is Medium Crack) AND (Size is Large) THEN (Grade is B)
8	IF Egg is (not Bloody) AND (Breakage is not Broken) AND (Crack is Medium Crack) AND (Size is Medium) THEN (Grade is C)
9	IF Egg is (not Bloody) AND (Breakage is not Broken) AND (Crack is Medium crack) AND (Size is Small) THEN (Grade is D)
10	IF Egg is (not Bloody) AND (Breakage is not Broken) AND (Crack is High crack) AND (Size is Large) THEN (Grade is C)
11	IF Egg is (not Bloody) AND (Breakage is not Broken) AND (Crack is High Crack) AND (Size is Medium) THEN (Grade is D)
12	IF Egg is (not Bloody) AND (Breakage is not Broken) AND (Crack is HighCrack) AND (Size is Small) THEN (Grade is D)
13	IF Egg is (Bloody) THEN (Grade is E)
14	IF (Breakage is Broken) THEN (Grade is E)

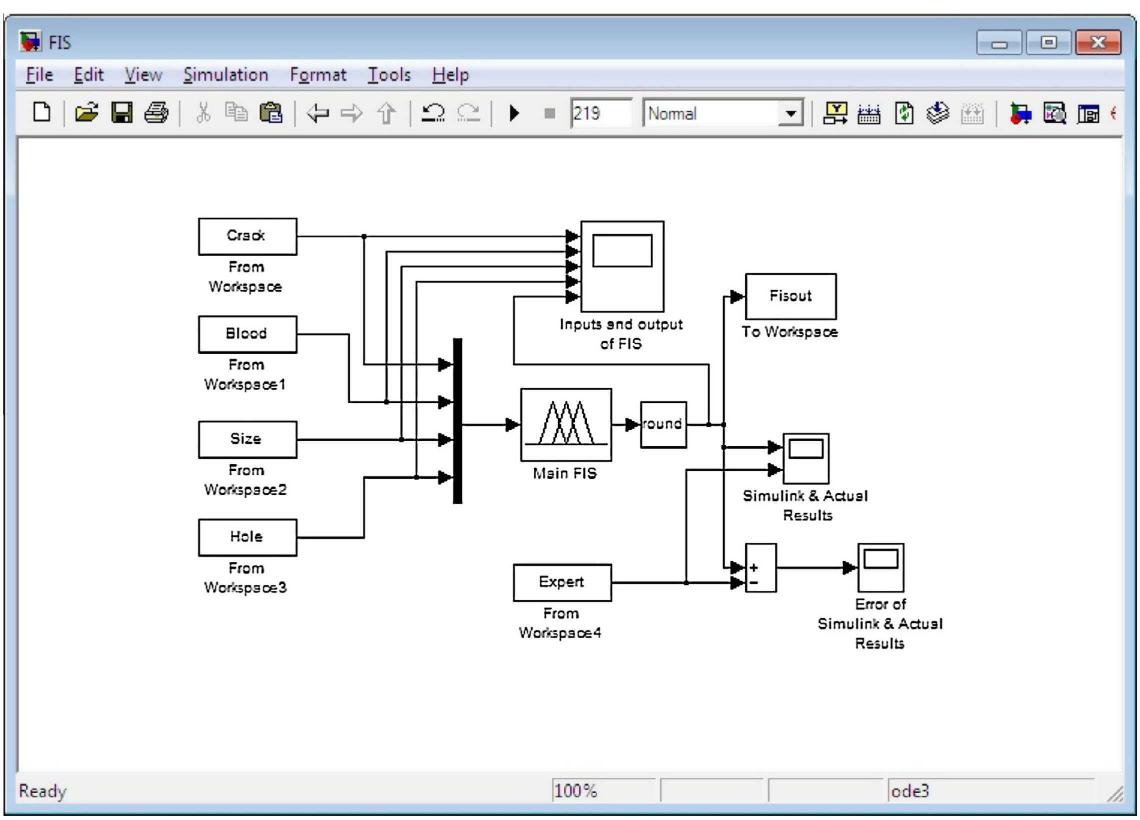

Fig. 8. The FIS model developed in MATLAB Simulink tool for egg grading.

Table 2
Comparison of results obtained from size algorithm and human expert. The bold values are the number of eggs that algorithm correctly predicted from total samples (100).

Class of sample		Image processing			–	
		Small	Medium	Large	Number	Accuracy (%)
Human expert	Small	**96**	4	0	100	96
	Medium	3	**93**	4	100	93
	Large	0	4	**96**	100	96
	Final result	99	101	100	285/300	95
	%	96.96	92.07	96	–	

nation of MFs function intervals for crack and size variables. Accordingly, 200 eggs having various crack sizes were prepared and classified in four classes (No crack, Low, Medium and High crack) by three experts. Also, 150 samples were provided and graded into three groups (Small, Medium and Large sizes). After classification, an image was captured from each sample and processed into algorithm for measuring of size and crack percentages. The obtained values were adjusted (adapted) with expert's judgment and the intervals for each class were obtained.

2.4.1. Simulink model for fuzzy classifier algorithm

The fuzzy logic classifier, designed for this study, was developed as a model in MATLAB Simulink toolbox [14]. The developed model using Simulink environment is shown in Fig. 8. Simulink tool has widely been used in model based studies of fault diagnosis system (Celik and Bayir, 2007; Yapici et al., 2009) and sorting (Omid et al., 2009). In this model, input variables were transferred from the MATLAB Workspace environment to the fuzzy logic classifier.

3. Results and discussion

Initially, the information about 500 eggs, obtained from image processing algorithm, was transferred to FIS and then results of Simulink's FIS simulation was compared with actual results obtained from experts.

To evaluate the developed algorithms, the confusion matrix (CM) was performed and the following equations were used for sensitivity and accuracy of algorithms (Omid, 2011):

$$CM = \begin{bmatrix} TP & FP \\ FN & TN \end{bmatrix} \tag{2}$$

$$Sensitivity = \frac{TP}{TP + FN} \times 100 \tag{3}$$

$$Accuracy = \frac{TP + TN}{TP + FP + TN + FN} \times 100 \tag{4}$$

where TP, FP, TN and FN are the number of true positives, false positives, true negatives and false negatives, respectively.

Table 4
Obtained result from breakage detection algorithm.

	Class		Number	Accuracy (%)	Average accuracy
Breakage	Intact	No crack	50	100	98
		Cracked	100	94	
	Broken		150	100	

3.1. Size algorithm

At the first step, all samples were classified by human expert and then classification was performed by developed algorithm. Comparison of obtained results from two methods is presented as a confusion matrix in Table 2. Results show that the designed algorithm had an adequate performance and in all mistakes, difference between two methods was only one class. As shown in Table 2, the overall accuracy of size algorithm was 95%, and 5% of egg samples were misclassified. Also the algorithm sensitivity was 95.01%. The size algorithm yielded in the medium class the lowest accuracy and sensitivity (93% accuracy and 92.07% sensitivity) and the highest sensitivity in small class (96.96%). Inspection of errors revealed that the reasons of misclassification were light noises and adjacency of class's intervals.

3.2. Crack algorithm

In this section, eggs with different degree of cracks were graded by expert in four classes and from each class, 100 specimens were separated randomly and after capturing images, the class of all samples was indicated by developed algorithm. The presented results in Table 3 show that the developed algorithm had a lower performance in low crack and high crack classes. The overall accuracy and sensitivity of crack algorithm was 94.5% and 96.68%, respectively. The highest accuracy was obtained for intact class (98%) and the lowest was obtained for high crack class. The high and medium crack classes had the highest and lowest sensitivity (100% and 90.65%, respectively).

3.3. Breakage algorithm

The expert judgment in egg breakage is a crisp variable (yes/no). So the algorithm was designed in a manner that output was crisp. To evaluate the developed algorithm, 150 intact samples and 150 broken samples were prepared and classified by the algorithm. Result of evaluation is presented in Table 4. The cracked egg without breakage must be classified in intact class (not broken). To enable the algorithm that grads cracked samples correctly, the threshold was fixed on 0.05. This value was obtained based on expert judgment and pre-examination on primary experiments. The intact samples included 100 cracked eggs and 50 eggs without any crack. The algorithm misclassified 6 cracked eggs in broken class. Investigation of misclassification revealed that in 4 specimens, light noises is the main reason of occurring mistake and in the segmen-

Table 3
Comparison of expert judgment and crack algorithm classification.

Class of sample		Image processing				–	
		Intact	Low crack	Medium crack	High crack	Number	Accuracy (%)
Human expert	Intact	**98**	2	0	0	100	98
	Low crack	4	**92**	4	0	100	92
	Medium crack	0	3	**97**	0	100	97
	High crack	0	3	6	**91**	100	91
	Final result	102	100	107	91	378/400	94.5
	%	96.08	92	90.65	100	–	

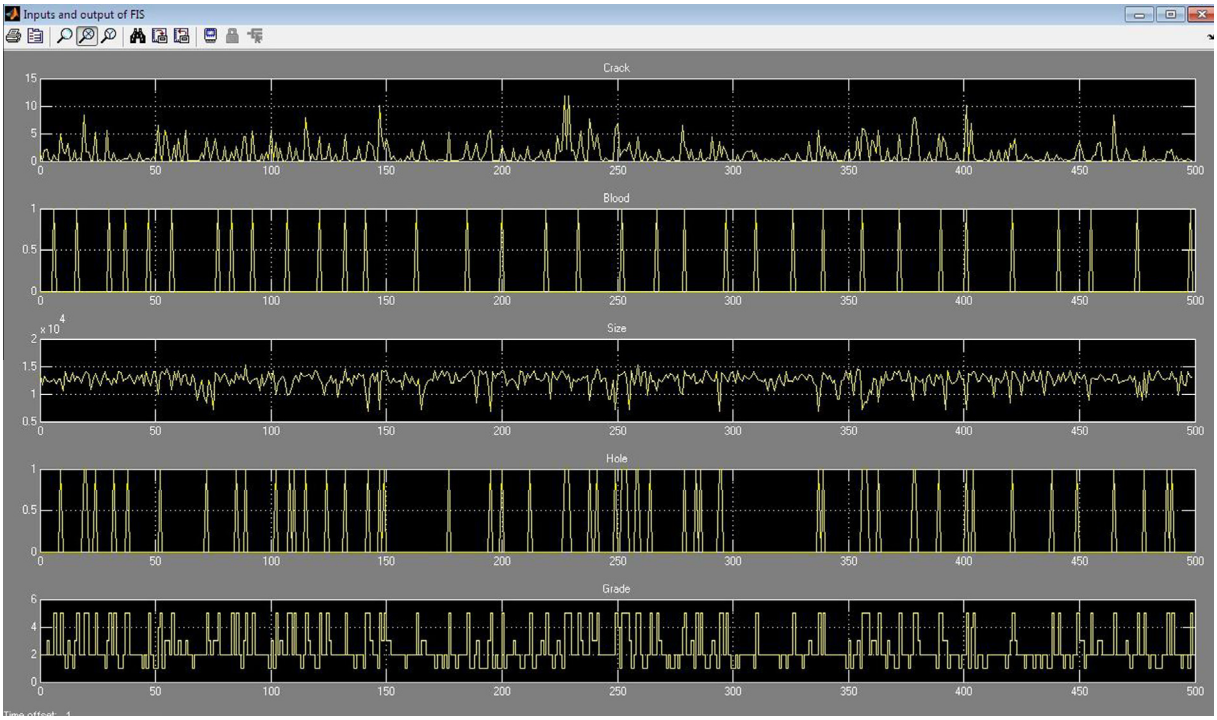

Fig. 9. Input parameters (top to bottom: crack, blood spot, size and breakage) and output (grade) for the evaluation of designed FIS.

tation algorithm, because of mentioned reason, separation process was implemented incorrectly and some parts of image was recognized as broken area. Only in two samples, the breakage algorithm made a mistake which may be as a result of fixing threshold improperly. Dehrouyeh et al. (2010) reported that the accuracy of blood detection algorithm has obtained 91%. Through the developed algorithms (crack, size, breakage and blood spot), the breakage algorithm had the highest accuracy with value of 98%.

3.4. Evaluation of fuzzy grading algorithm

The fuzzy grading algorithm, classifies egg based on obtained data from image processing algorithms. The main part of fuzzy grading algorithm is fuzzy inference system. Therefore this section was evaluated using Simulink tool in MATLAB software. Fig. 9 shows the variation of inputs and the effect of them on output (egg grade) for 500 specimens.

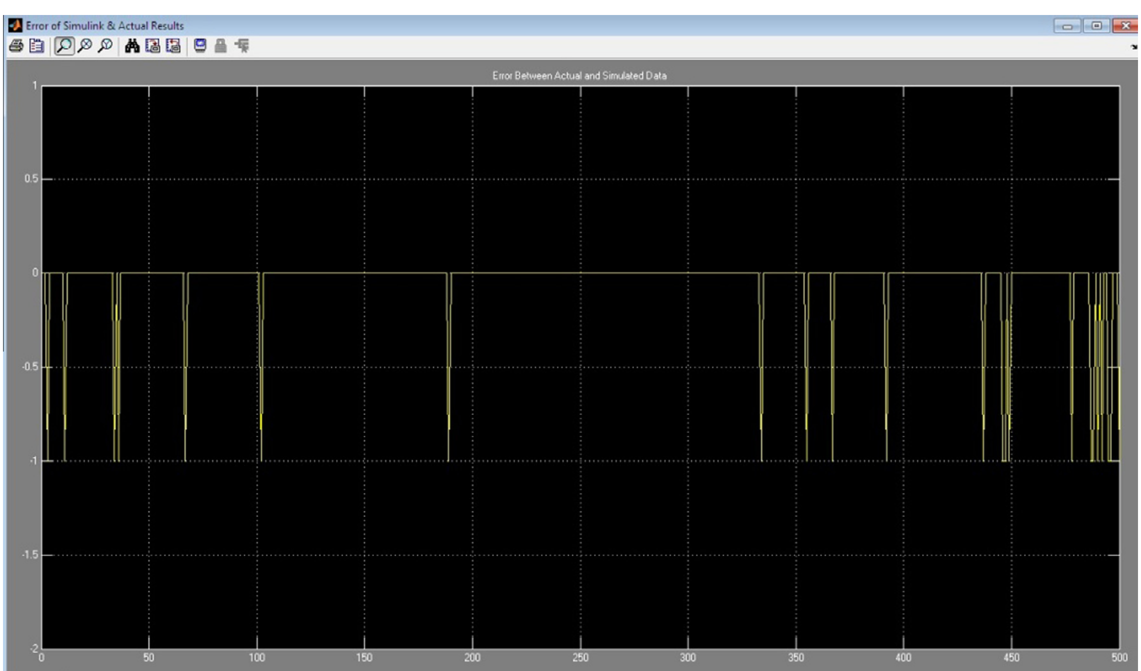

Fig. 10. The error graph of Fuzzy inference system for egg grading compared with actual values.

In Fig. 10 differences between simulated and actual results is presented. When the ideal result could be achieved that no difference was observed between outputs of two methods and as a result the error graph showed zero value. But existence of any noise in error graph is due to disagreement between FIS classification and expert's judgment for a particular sample. From 500 samples, in 23 cases of egg grading a difference was observed between Simulink's results and expert classifications. Therefore, the overall accuracy of designed system was 95.4%. In Fig. 10 a small and negative noise (1 class) was observed. This means that the FIS system classified the 23 samples in a higher class by 1 unit. Nevertheless the system did not classify the wastage specimens in other classes and errors were occurred in intermediate classes only. By varying of thresholds in image processing algorithms and intervals in fuzzy sets, the grading system can be turned into more or less stringency mode.

4. Conclusion

In this research, an expert system was designed and developed for egg grading using machine vision system and fuzzy logic tool. Results showed that designed algorithm had adequate ability to determine the needed parameters. By surveying of errors occurred during classification, it was found that noises and condition of eggshell such as shell thickness were the reasons of error happen. Some of these errors were corrected and others were inevitable. Results of simulation showed that fuzzy grading algorithm had a good efficiency (performance). Comparison between human experts and FIS classifier indicated that designed system outperformed and was more accurate than experts.

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