



Recognition of Fill and Empty Walnuts Using Acoustic Analysis and Fuzzy Logic

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ARTICLE INFO

ABSTRACT

Keywords:

Fuzzy logic;
Sorting;
Sound processing;
Walnut

To increase the amount of export and marketability of walnuts, a quick, cheap and non-destructive sorting approach should be used. The overall objective is to sort the full, half full and empty walnuts relying on fuzzy logic and sound analysis methods. To sort the walnuts the sound processing technique was used. In this regard, effective parameters on sorting and quality such as: size and shape of walnut were studied. For this purpose, 300 dried walnuts were randomly selected from a walnut orchard for use in experiments. An electronic system consisting of a computer, a microphone, and a mechanical section consisting of a sound chamber were designed to measure the sound intensity of a walnut. At this stage, each walnut was released in three directions: back, side and abdomen 30 cm above the surface of the sound chamber. The sounds were recorded by a microphone with acoustic beats on a sound chamber made of wood and a 45-degree slope. The data from the sound signals were stored in the time domain on the computer and then processed by the MATLAB software. In order to eliminate the ambient noise of signals, Kalman filter algorithm was used to achieve high accuracy and fast convergence. Then these data were analyzed by fuzzy logic method. In this research, WEKA software and J48 algorithm have been used to classify walnuts based on their filling and using the features extracted from the walnut collision with a wooden plate. In order to classify walnuts according to the fullness of walnut kernels, a scientific and innovative index called Full Kernel Index (FK) was used. The results of this study showed that for classification of walnut, decision trees due to simplicity of structure and creation of fuzzy rules and threshold values of membership functions make fuzzy inference system with high accuracy. The final fuzzy model was presented to classify walnut into two classes with 0.087% separation accuracy and 3 classes with 0.080% separation accuracy.

Introduction

Walnut is a nut crop that is very popular and largely consumed in the world (Sarikhani et al., 2021). It is a nutritionally valuable crop that is of high demand around the world (Hassankhah et al., 2017). High nutritional value of walnut kernel makes it a popular nut all around the world (Chatrabnous et al., 2018). Nowadays grafting and budding have become appropriate methods in walnut propagation (Thapa et al., 2021; Raoufi et al., 2020; Farsi et al., 2016 and

2018; Ebrahimi et al., 2006). The area under cultivation and production is increasing every year, so that according to the statistics of the World Food and Agriculture Organization (FAO), the export of this product in 2018 was about 1.8 billion dollars (Heidari et al., 2019). Iran is the origin of walnuts and is the fourth largest producer in the world, which has more than 10 percent of the world's fruiting walnut cultivation area and more than 9% of the world's walnut production, but

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Received: 22 December 2020; Received in revised form: 7 February 2021; Accepted: 15 March 2021
DOI: 10.22034/jon.2021.1918546.1103

Iran's share of the global market for this product is only 0.35% of walnut exports and 0.7% of walnut exports are In shell (Walnut Knowledge and Industry Coordination Center, 2018). One of the most important ways to increase the export of agricultural and horticultural products is proper sorting of products. Various methods are used in the separation and sorting of agricultural products, among which non-destructive and non-contact methods are very important due to their high separation speed and observance of hygienic principles. In the case of the walnut crop, one of the solutions to reduce the non-uniformity of this crop in increasing its exports is to grade the walnut with walnut shell or kernel (separate husk) using a non-destructive method (Khalifa *et al.*, 2013). In the processing of similar products such as pistachios, the separation of hollow and immature pistachios is of great importance. At present, methods such as flotation, wind and dry pond are used in pistachio processing terminals to separate hollow pistachios. The devices currently used to separate hollow pistachios from the kernel have drawbacks. These disadvantages include increased risk of Aflatoxin contamination, tissue damage, high energy consumption, low separation accuracy, high volume of the device, high noise generation and high dust generation (Ghezavati *et al.*, 2013).

In a study, they designed an intelligent walnut quality recognition system based on acoustic analysis and a multilayer neural network (MLNN) to classify walnuts into three classes. In this method, walnuts were divided into empty, medium and whole groups based on the amount of filling. In order to produce sound signals, a polished steel sheet with a diameter of 150 mm and a slope of 60 degrees was used. 326 samples were used to evaluate the system performance. After feature production, 60% of the samples were selected for training, 20% for validation and the remaining samples for testing. The optimized MLNN model had architecture of 4–12–326. The selection of the optimal

model was based on the evaluation of the mean square error and the correct separation rate (CSR). CSR rates for full, medium and empty walnuts were 97.67, 80.00 and 93.33%, respectively. The average total weight in the system accuracy for the structure 4-12-326 was equal to 95.38%. This means that only 4.62% of walnuts were not classified. It can be argued that the developed system was sufficiently able to correlate the acoustic properties with the fullness of the walnut fruit (Minae *et al.*, 2013). In the classification of closed-mouth nuts such as walnuts, it was stated that volumetric mass is a good indicator of the emptiness of these products, which has not yet been provided a quick and non-destructive method for its diagnosis. In this study, to produce sound, a design was presented that obtained the sound of rolling a walnut, which included a steel profile that increased the slope of the rolling surface by increasing the displacement of the taller base in the horizontal direction. The entire surface of the profile was polished to make the pure steel surface perfectly shiny but at the same time compact, leaving the walnut to have at least a head. In another study, a system was designed to produce the sound of a walnut that could strike a small hammer at controlled intervals into the breadth (suture) of the walnut and receive a microphone at a distance of one millimeter from the other breadth (suture) to receive the acoustic response of the walnut for analysis (Khalesi *et al.*, 2012).

(Hajizadeh *et al.*, 2014) In a study, they presented a fast, accurate and non-destructive method for sorting walnut fruits based on their specific gravity using the visual machine system. To obtain the specific gravity, the mass of 60 walnuts was measured using a digital scale with an accuracy of 0.01 g and their volume was calculated by three methods of effective radius, surface area and total elements through image processing. Specific mass (mass to volume ratio) was determined in each method. Based on the thresholds selected for sorting, walnut fruit was graded in 3 different grades.

The values of coefficient of determination for the three methods of effective radius, surface area and total elements were 0.82, 0.94 and 0.87, respectively. The surface area method was more appropriate than the other two methods due to having a higher coefficient of determination. Finally, the actual and calculated values of specific gravity were compared based on selected thresholds. The sorting error in the three methods of effective radius, surface area and total elements were 6.6, 3 and 6.6%, respectively. Signals are a function of one or more independent variables that contain information about a physical or biological phenomenon. These signals are electrical, mechanical or chemical. Sometimes the signals are mixed together or affected by noise. The purpose of processing the received signals is to separate the desired signal from the mixed and noisy signals and then to extract the useful signal parameters. One of the most important signals in diagnostic systems is audio signals. In recent years, due to the growth and development of audio signal processing techniques, as well as the capabilities of newer microphones and efforts to find accurate and non-contact diagnostic methods, the use of voice in automatic diagnostics has received renewed attention. Research has been done in this field (Khakrangin *et al.*, 2015).

Omid *et al.* (2010) designed and evaluated an intelligent sorting system for open and closed-shell pistachio nuts. The system included a feeder, an acoustical part, an electronic control unit, a pneumatic air-rejection mechanism and ANN classifier. The recognition was based on combined PCA of impact acoustics and ANN classifier. To generate useful features, both time and frequency-domain analysis of recorded sound signals were performed. In a recent study, a new method based on MV system was developed for egg volume prediction.

One of the modeling techniques in the field of artificial intelligence is fuzzy inference systems. Since fuzzy logic is based on real logic used in the human

mind, it is more efficient than other methods such as neural networks in issues where individual tastes play a decisive role (Korol, 2012). One of the challenges in this system is finding the if-then rules between input and output variables. These rules are seldom specified by experts as self-aware rules or are obtained according to experimental data using methods such as mean c clustering, descending clustering, search tables, etc. (Labafi *et al.*, 2008). The search table method follows a simple algorithm and is more accurate than other methods where the amount of data is small.

Khakrangin *et al.* (2008) identified five walnut genotypes using neural network techniques. In this way, they used two techniques of post-diffusion and self-organized neural network to identify these genotypes. Previous studies have shown that the importance of using acoustics to classify agricultural products is very high. Acoustic diffusion device has been used to separate open and closed pistachios (Omid *et al.*, 2010). Separation of empty and full hazelnuts has also been done by percussive acoustic method (Ionaran *et al.*, 2008).

aderi (2017) reported that, a combination of audio signal processing techniques and artificial neural network provided a method for classifying and grading hazelnuts. To this end, a system was designed and built in which a steel plate with a thickness of 3 mm and dimensions of 130 mm and 130 mm was used to produce audio signals. To evaluate the performance of the system, 400 hazelnuts were used of which 100 were large healthy hazelnuts, 100 were healthy small hazelnuts, 100 were broken hazelnuts and 100 were empty hazelnuts. The most suitable neural network model for grading hazelnuts into groups of large, healthy, small, healthy, broken and hollow SOM obtained as a 4-1-2000 structure. Finally, the accuracy for detecting large hazelnuts was 97.1%, small hazelnuts 98.2%, broken with different dimensions 94.1% and hollow 89.7%, indicating an overall accuracy of 94.8%

offline. Using self-regulated neural network type and online survey, accuracy (79.2%) was obtained for large hazelnuts, (68.5%) for small hazelnuts (67.3%), broken hazelnuts with different dimensions and (69.4%) hollow hazelnuts, which showed the overall accuracy (71.1%) in online mode. Kurtulmu *et al*, 2018) developed a prototype system for classification of chestnuts using impact sound and computational intelligence methods based on moisture contents. Three different moisture contents (35%, 45%, and 55%) of Chest nut were used in classification applications. The highest classification rate of 88% was achieved for the SVM-RFE algorithm. (Farhadi *et al.*, 2020) introduced a method for sorting and grading hazelnuts by combining audio signal processing and artificial neural network techniques. For this purpose, a system was designed and developed in which the sound produced, due to the collision of the hazelnut with the steel disk, was transmitted to the computer via a microphone placed under a steel disk. Seventy percent of the extracted data signals were used for training, 15% for validation and the rest of the data for artificial neural network experiments (Perceptron multilayer network with Levenberg-Marquardt learning algorithm). Model optimization and the number of neurons in the hidden layer were performed based on mean square error (MSE) and predictive accuracy (PA). A total of 2400 hazelnuts were used to evaluate the system. The optimal structure of the neural network for sorting and grading hazelnuts was 4-21-3 (four neurons in the input layer, 21 neurons in the hidden layer and three outputs that are the optimal classification). This neural network (NN) was used to classify hazelnuts as large, small, hollow or damaged. The results showed that 96.1%, 89.3% and 93.1% accuracy were obtained for large / small, hollow or damaged hazelnuts, respectively.

Accordingly, the main purpose of this study is to investigate the possibility of using audio signal processing technique and fuzzy logic to grade walnuts.

Materials and Methods

In this study, in order to determine the quality of walnuts, two parts of software and hardware have been used to determine the fullness of dried walnuts. The software part includes programs in MATLAB environment for processing the sound of a walnut collision to a level and AVS software for receiving the sound and sending it to the computer and WEKA software as a fuzzy logic classifier. The hardware part also consists of two parts, electronic and mechanical, the electronic part includes computer, and microphone and the mechanical part includes sound chamber.

300 walnuts used in the experiments were randomly selected from a walnut orchard of Tuyserkar cultivar, located in Malayer city in Hamadan province in the 2019. In order to have the same genotype of walnuts, the fruits on a tree were used. The walnuts were dried in the sun for a week. Data from audio signals in the time domain were stored on a computer for later analysis. At this stage, the sounds were received and recorded by the acoustic impact by the sound chamber and the microphone in it. MATLAB software was used for impact noise analysis. For each walnut, sound recording was performed from three directions: back, side and breadth with a release height of 30 cm from the surface of the sound chamber. The schematic of the walnut quality measurement and separation system is shown in Fig. 1.

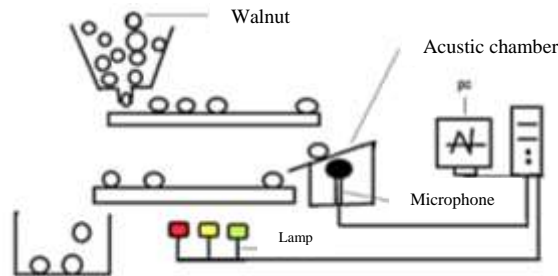


Fig. 1. Schematic of Walnut Quality Measurement System

The weight of walnuts measured by a digital scale. Each walnut weighed and the weights measured, which included the weight of the walnut kernel and skin, were recorded. In the end, the walnuts were broken and their kernel weight was recorded. The volume of walnuts was

measured by liquid transfer method and their dimensions were measured by a caliper. Table 1 shows an example of values related to the dimensions and weights of walnuts.

Table 1. Weights, Volumes and Different Dimensions for 15 Sample Walnuts

Number	Walnut Kernel (Gr)	Total Weight (Gr)	Volume (Ml)	Breadth (Suture) (Cm)	Width (Cm)	Length (Cm)
1	5.25	10.94	21.5	3.31	3.43	4.3
2	4.62	9.79	22.5	3.6	3.4	4.4
3	2.47	7.86	20	3.34	3.44	3.94
4	6.18	11.83	22	3.35	3.53	4.02
5	3.2	8.91	21	3.43	3.35	4.06
6	1.68	7.36	20	3.34	3.37	4.03
7	5.11	11	21	3.49	3.39	4.23
8	3.28	8.35	18	3.45	3.26	3.82
9	4.49	11.34	27	3.78	3.74	4.37
10	2.13	8.35	20	3.43	3.37	4.19
11	5.23	11.84	23	3.63	3.48	4.4
12	3.32	8.61	21	3.47	3.57	3.16
13	5.38	10.93	20	3.55	3.39	4.15
14	2.99	8.17	21	3.44	3.37	4.1
15	3.02	7.7	20	3.36	3.26	4.24

To receive sound, a chamber had to be built that could collect the sound of walnuts hitting a surface. A wooden sound chamber was selected for this purpose. The slope of the impact surface (surface) in this

chamber was made in order to prevent the head and the collision of the walnut on the surface with an angle of 45 degrees. The use of wood was used to make the sound chamber as desired (Fig. 2).

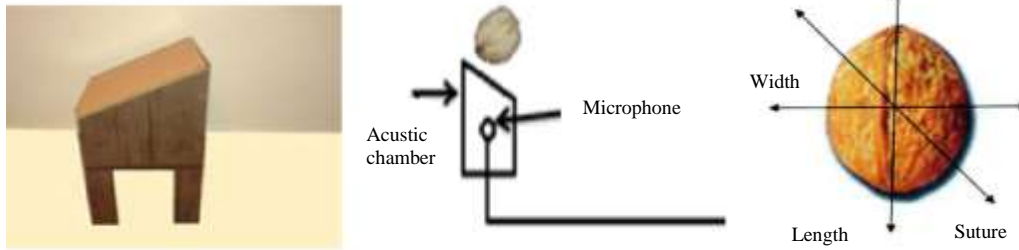


Fig. 2. Sound Tank Schema

The microphone used was capacitive and was placed at a distance of five cm from the surface of the sound chamber. This type of microphone is resistant to pressure and heat, but is sensitive to humidity and loud noises.

In order to eliminate the ambient noise of signals, Kalman filter algorithm was used to achieve high accuracy and fast convergence. Since the Kalman filter is very efficient in detecting and extracting periodic noises that are made of different sinusoidal components and possibly with unknown frequencies or variable with time, this approach was used to eliminate noise.

Fig. 3 shows the block diagram describing the desired classification system, each of which will be briefly described below. The microphone's job is to transmit the sound of the walnuts hitting the wooden board to the primary processing section via the sound card. In the primary audio processing section, operations such as normalizing facial data were performed. The purpose of feature extraction is to select the meaningful features in the received signal that are required for

proper classification. The input signal to the feature extraction block represents the digital signal in the time domain and its output is the feature vector. An example of a simplified signal from the original signal that has a vector length of 300,000 points reduced to 500 points is shown in Fig. 4. Signal processing methods in the time domain require peak, mean, maximum, minimum, sum, variance, elongation, median, and skew values to extract the properties. In the sound classification block, the classification was based on fuzzy logic. During the training process, signals from specific classes were given to the classifier. The classifier adjusts its weights in the training phase so that it can reproduce the results of the specific classification in the best possible way. In this study, WEKA software and J48 algorithm were used to classify fuzzy logic. In the information-based interpretation block, the system can make decisions against new inputs based on previous information and determine the new input class based on the training it has received.



Fig. 3. Block Diagram of the Classification System

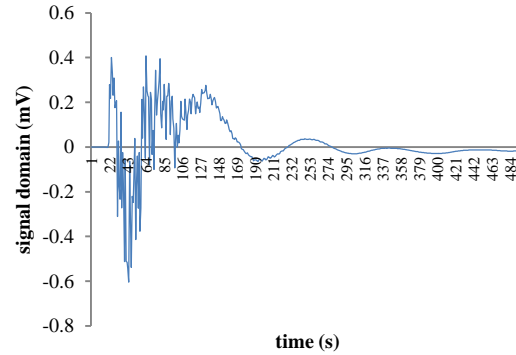


Fig. 4. An example of a simplified sound signal from the original signal

Fuzzy rules

Using the created decision tree, the fuzzy rules were created as if-then expressions, and all of these rules were placed in the fuzzy model with equal importance. Of course, the order of the rules does not matter. The rules created in the 2nd classification are 12 rules, for example 5 rules are:

1. If (skew is skew1) and (sum is not sum1) then (output is Empty) (1)
2. If (skew is skew1) and (sum is sum1) and (median is median3) then (output is Fill) (1)
3. If (skew is skew1) and (sum is sum1) and (median is median2) and (max is max4) then (output is Empty) (1)
4. If (skew is skew1) and (sum is sum1) and (median is median2) and (max is max1) then (output is Empty) (1)
5. If (skew is skew1) and (sum is sum1) and (median is median2) and (max is max2) then . . .?

The rules in the 3-class classification are a total of 37 rules, for example 5 rules are:

1. If (skew is skew1) and (variance is var1) then (output is Empty) (1)
2. If (skew is skew1) and (variance is not var1) and (stdev is stdev2) then (output is Empty) (1)

3. If (skew is skew1) and (variance is not var1) and (median is median2) and (max is max4) then (output is Empty) (1)

4. If (skew is not skew1) and (average is avr1) and (max is max1) then (output is Medium) (1)

5. If (skew is skew9) and (average is not avr1) then (output is Empty) (1)

Classification with decision tree

Decision trees, as part of data mining systems, are a powerful tool for classification. In this research, WEKA software and J48 algorithm have been used to classify walnuts based on their filling and using the features extracted from the walnut collision with a wooden plate. In order to classify walnuts according to the fullness of walnut kernels, a scientific and innovative index was used. The full kernel index (FK) was defined based on Equation (1).

$$Fk = \frac{(Wt-Wk)^2}{Vt} \tag{1}$$

Where Wk is the weight of the kernel, Wt is the total weight, and Vt is the total volume of the walnut. The distribution of this index among the walnut samples is as shown in Fig. 5.

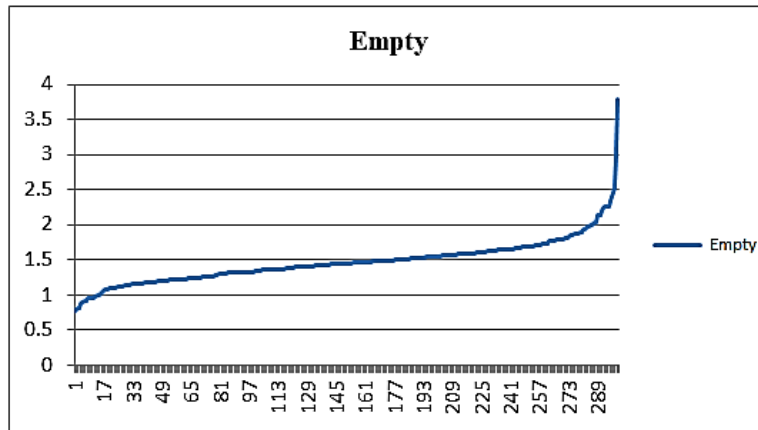


Fig. 5. Scattering of the Fullness Index (FK) Among Walnut Samples

An example of a decision tree created by WEKA software is shown in Fig. 6. To extract the rules, you have to move from the highest node to the leaves of the

tree. For example, if the skew is less than -1.397656 and the sum is less than 9.651635, then the walnut in question is empty.

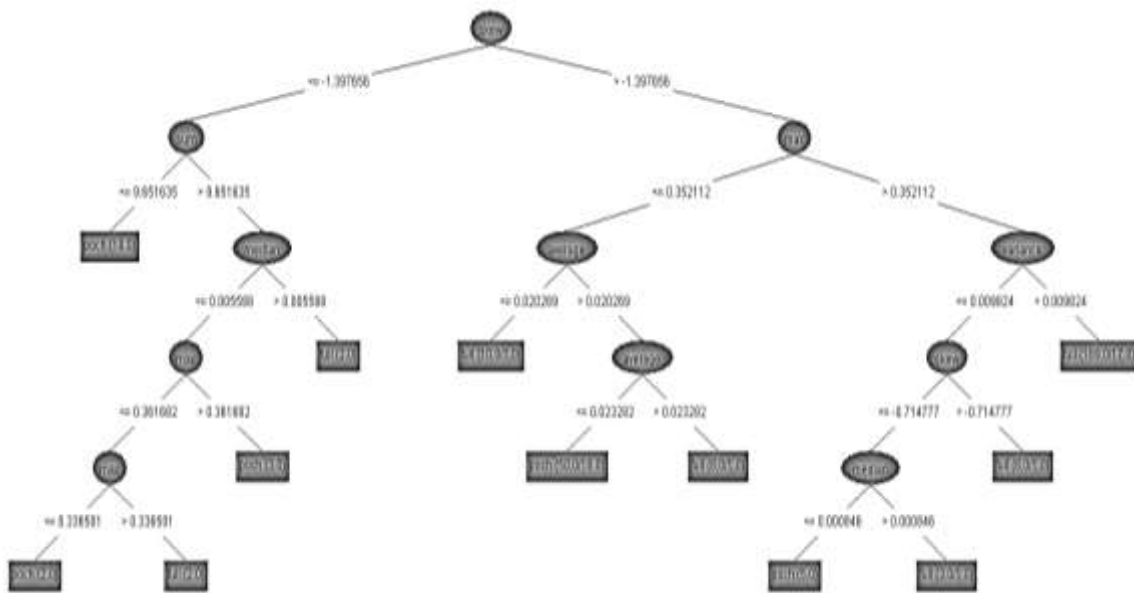


Fig. 6. An Example of a Decision Tree Created by Weka Software

Walnuts were classified in two ways. In the first method, walnuts were classified into two groups of full walnuts and hollow walnuts by fuzzy logic. The number of spectra trained in this step is given in Table 2. At this stage, due to the proximity of the data to each other, it was not possible to divide walnuts into more than two categories. As an example, Fig. 7 shows the proximity of the data to each other in the mean property,

respectively. Due to the large volume of features, other features are omitted. The learning and test stage settings in the 3 classes are presented in Table 3. Decision trees show the relationship between the characteristics of the signal spectrum resulting from the collision and the state of the nut. Tracing a branch from the main node to the leaf leads to a walnut state, and decoding the information in each tree branch into if-then-fuzzy

sentences provides the rules for fuzzy walnut classification. Obviously, in each tree, the highest node is the best node to classify. Other properties are in descending order of importance in decision tree nodes. Also, in decision trees, only those features of the spectrum that are important for correct classification are included, and features that are not important for the classification of walnuts are kept out of the model. The

data distribution level for the set of features that make up a class is indicated by numbers in parentheses in the decision tree and in front of the walnut class. Thus, the first number in parentheses indicates the number of data that can be correctly categorized by the attribute set, and the second number indicates the number of data that is incorrectly placed in that category.

Table 2. Learning and Test Stage Settings in Two Classes

Classification Label	Number of Training Stage Spectra	Number of Spectra Tested	Total
Empty Walnuts	53	28	81
Fill Walnuts	146	73	219

Table 3. Learning and Test Stage Settings in Three Classes

Classification Label	Number of Training Stage Spectra	Number of Spectra Tested	Total
Empty Walnuts	33	23	56
Half Full Walnuts	70	47	117
Fill Walnuts	76	56	127

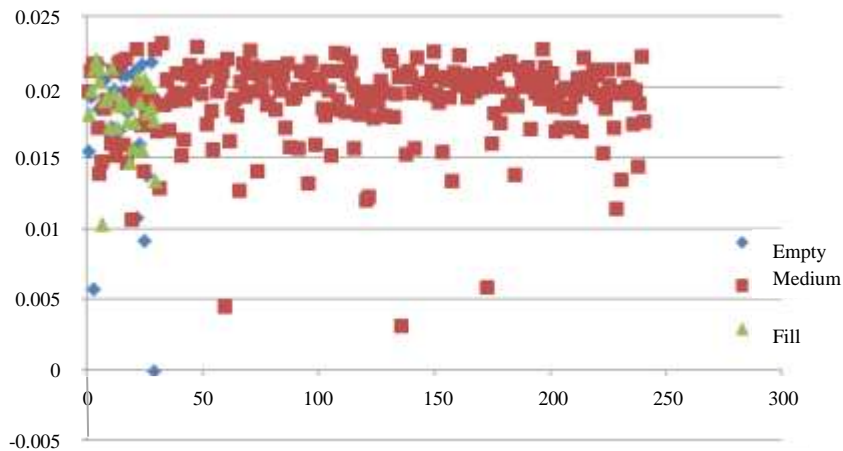


Fig. 7. Data Scatter in the Mean Property

Results

Input membership functions

Considering the values obtained for the statistical properties of the collision spectra on the decision trees, based on which branches of the decision tree were created for the walnut classes, the membership functions for those properties were specified in the MATLAB software as follows. Fig. 8 and Fig. 9 show the membership functions of two classes and three classes

for the input of walnuts, respectively, according to the decision tree of Fig. 6. From Fig. 10 it can be seen that the number 9.6 is a threshold for the membership value of the sum attribute. Before this value the membership function produces the numeric value 1 and after that it is assumed to decrease linearly. The membership function that expresses such a phenomenon is called smf (A

Membership Function). In this research, this function was used as a membership function to plot points in the input space to a membership value. If the maximum attribute value is less than or equal to -0.12725 , the membership function, which is specified between scales 0 to 1, assigns a membership value of 1, meaning that it is the

first mean. If the threshold value is greater than -0.012725 , the membership function generates a membership value of zero. Creating membership functions for other attributes in decision trees was the same throughout this study.

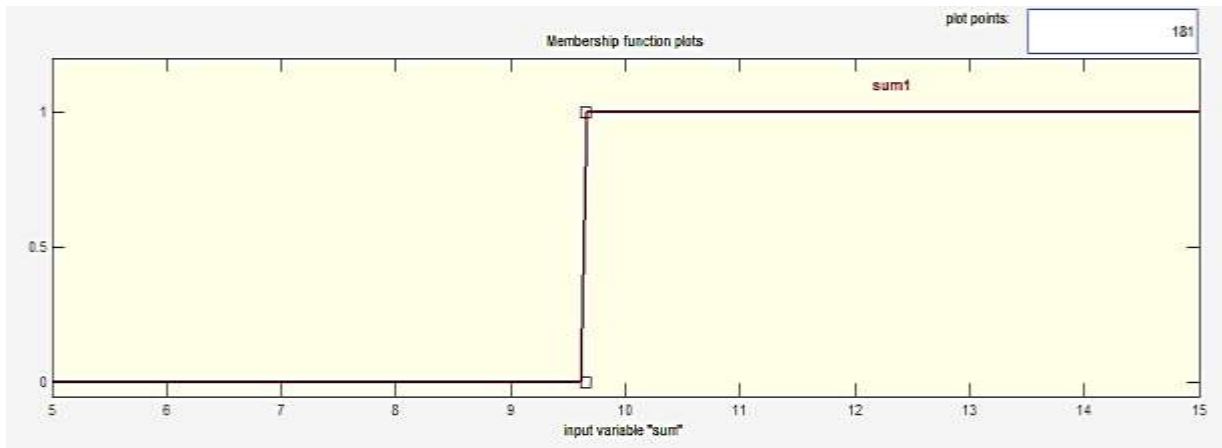


Fig. 8. Membership Function for the Average Property in the Two-Class Classification

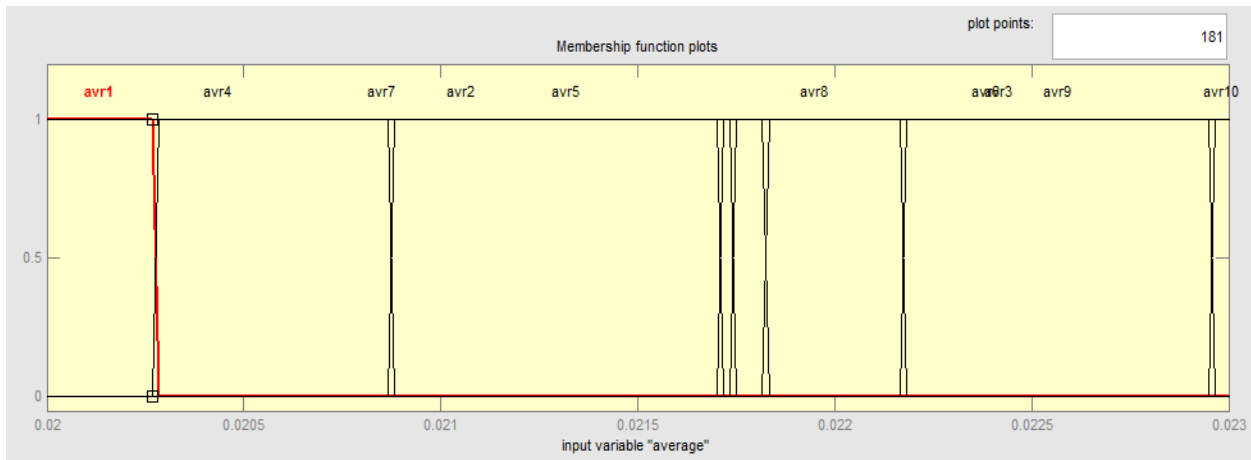


Fig. 9. Membership Function for the Average Property in the Three-Class Classification

Output membership functions

The output of the fuzzy classifier is actually the same class of walnuts labeled as Full walnut, Empty walnut, and Medium Walnut. Therefore, there are two outputs for the fuzzy classifier and for them four

membership functions with equal range in the range 0 to 1 were created. So that the range of 0.5-0 was considered for the class of full walnuts and the range of 0.5-1 for the class of empty walnuts were considered.

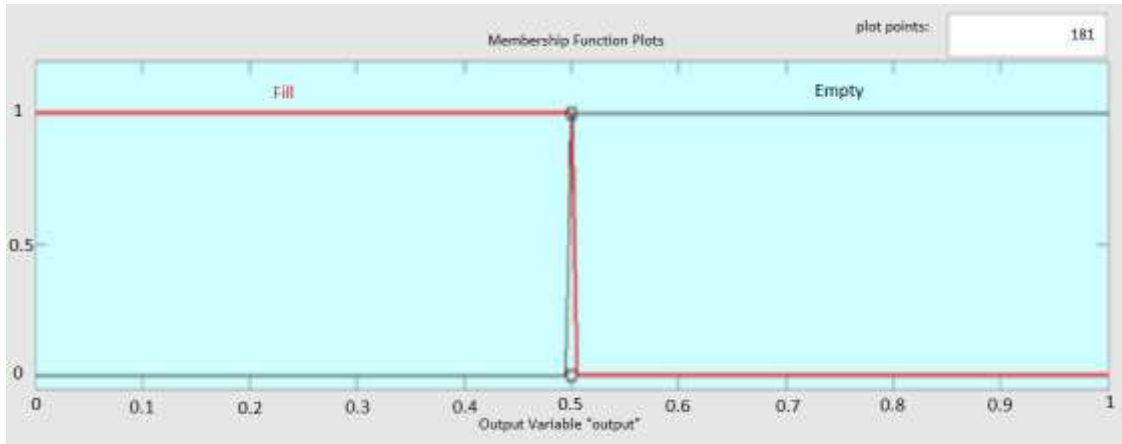


Fig. 10. Membership Functions for Fuzzy Output

Discussion

Fuzzy output

The output of the created fuzzy system can be viewed in the "Rule viewer" editor. The Rule viewer created is shown in Fig. 11 of the 2-Class Classifier. In this form, each row corresponds to one of the created rules. The first 6 columns from the left in the Fig. represent the membership functions max, median, sum, skew, average, variance, respectively. The seventh column also corresponds to the membership functions created for the fuzzy output. By moving the slider on the

blocks of each of the input membership functions, different outputs can be obtained. Using the input samples for the results, median, sum skew, average, max, variance, the rules were tested as follows. For skew input values of -1.64 and variance values of 0.00809, which corresponds to the fuzzy law in the classification of 2 classes, and the output corresponds to that class of empty walnuts, which includes the third and fifth blocks of fuzzy output.

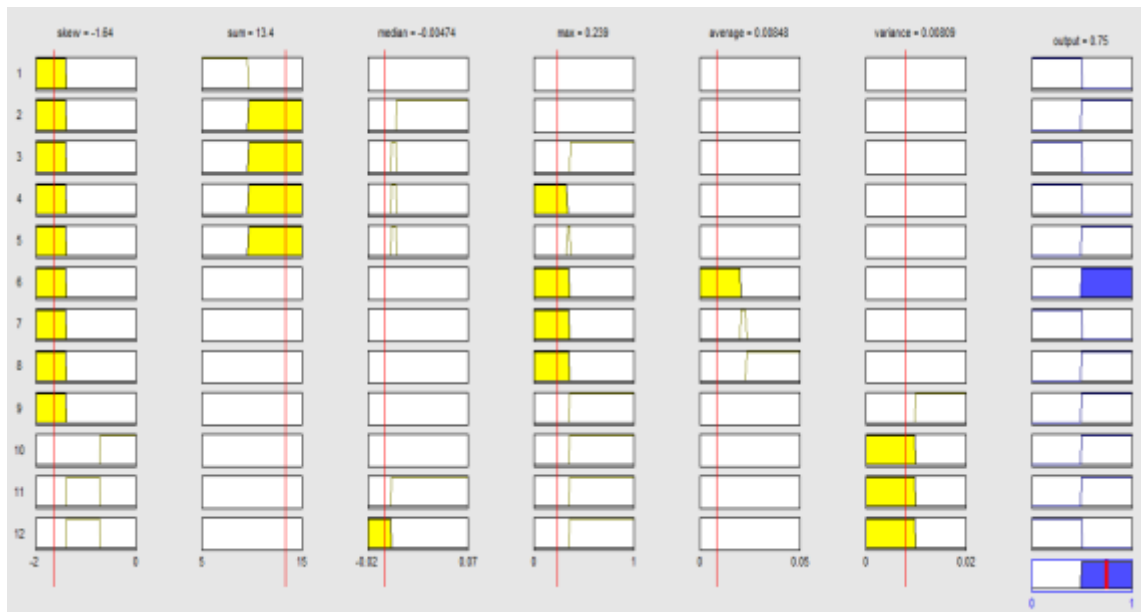


Fig. 11. Rule Viewer Two Classes Created For a Sample of Data

Conclusions

In this research, non-destructive acoustic test method was used with fuzzy logic technique to classify walnuts. The density of the walnut is directly related to the intensity of the signal generated by the collision of the walnut with the wooden surface, and through this, it can be realized whether the walnut is full, half-full or empty. In the case of walnut classification, decision trees facilitate a high-precision fuzzy inference system due to the simplicity of the structure and the creation of fuzzy rules and threshold values for membership functions. The final fuzzy model presented for classifying walnuts into 2 classes with accuracy of 0.087 percent separation and 3 classes with accuracy of 0.080 percent separation was obtained. What was remarkable about the separation was that it was more difficult to separate medium walnuts from the other two categories.

Declarations

Funding (Not applicable)

Availability of data and material (Not applicable)

Code availability (Not applicable)

Authors' contributions (All authors contributed to the study conception and design. Material preparation, data collection and analysis were performed by [author1], [author2], and [author3]. The first draft of the manuscript was written by [author2], and [author3] and all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.)

Acknowledgements

We wish to thank the Islamic Azad University, Takestan Branch, Takestan, Iran.

Conflicts of interest/Competing interests

(The authors declare that they have no conflict of interest)

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