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Automatic Grading of Emperor Apples Based on Image Processing and ANFIS

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ABSTRACT

Mass-based fruit classification is important in terms of improving packaging and marketing. Mass sizing can be accomplished by direct or indirect methods. In this study, 100 samples of Emperor Apples were randomly selected from an orchard in Kermanshah, Iran (longitude: 7.03 °E; latitude: 4.22 °N). All tests were carried out in Physical Laboratory, Faculty of Agriculture Engineering, Razi University, and Kermanshah, Iran. Fourteen parameters were obtained by image processing for each apple. Several mass modeling were made using ANFIS and linear regression methods. In the best model for ANFIS, linear and nonlinear regression, R^2, SSE, and MSE were 0.990, 276.58, 13.17, 0.856, 15980.96, 166.47 and 0.791, 24512.16, 255.35, respectively. So, a mass-based sorting system was proposed with machine vision system and using ANFIS method that could obtain apple mass without contact with the fruit. Benefits of this system over mechanical and electrical systems were: 1- Easier recalibration of the machine to the groups with different sizes, and 2- Reaching more accurate mass measurement and higher operating speed using indirect grading.

Keywords: SPSS; Packaging; Marketing; Machine vision; Fuzzy inference system; Sorting

Görüntü İşleme ve ANFIS ile Emperor Elmasının Otomatik Sınıflandırılması

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ÖZET

Ağırlık tabanlı meyve sınıflandırma, paketleme ve pazarlanmanın iyileştirilmesi açısından önemli bir terimdir. Ağırlıklarına göre sınıflandırma doğrudan veya dolaylı yöntemlerle gerçekleştirilebilir. Bu çalışma için, Kirmanşah, İran'da (Boylam: 7.03 °E; Enlem: 4.22 °N). bir meyve bahçesinden rastgele 100 Emperor Elma örneği seçilmiştir. Tüm testler Ziraat Mühendisliği Fakültesi, Razi Üniversitesi, Kirmanşah, İran Fizik Laboratuarında yapılmıştır. Her elma için görüntü işleme ile ondört parametre elde edilmiştir. ANFIS ve doğrusal regresyon yöntemleri kullanılarak çeşitli ağırlık modelleri geliştirilmiştir. En iyi model sırasıyla ANFIS, doğrusal ve doğrusal olmayan regresyon için, R^2, SSE, ve MSE için 0.990, 276.58, 13.17, 0.856, 15980.96, 166.47 ve 0.791, 24512.16, 255.35 şeklindedir. Yani, makine görme sistemi ile meyve ile temas etmeden ağırlık tabanlı elma sınıflandırması sağlanabilir. Mekanik ve elektrik sistemleri üzerinden bu sistemin faydaları şunlardır: 1- Farklı boyutlarda gruplar için makinenin tekrar kalibrasyon kolaylığı, 2- Dolaylı sınıflandırma kullanılarak daha doğru ağırlık ölçümü ve yüksek çalışma hızına ulaşma.

Anahtar Kelimeler: SPSS; Paketleme; Pazarlama; Yapay görme; Bulanık çıkarım sistemi; Ayırma

1. Introduction

Product grading is done with the aim of providing products with high quality and the same shape, volume, and weight. To carry out each of these objectives, there are several methods such as mechanical methods and electrical methods that are classified as direct and indirect methods, respectively. If a suitable method is used for data analysis, indirect method is better than other methods. Sabszi et al (2013) developed seven mass models for Blood orange based on ANFIS and linear regression. Results showed that ANFIS has better performance than linear regression method. In the best model, the coefficient of determination (R^2), sum square error (SSE) and mean square error (MSE) for ANFIS and linear regression were 0.983, 65.86 and 2.9 and 0.927, 936.26 and 9.65, respectively.

Mizushima & Lu (2013) proposed an image segmentation method for apple sorting and grading using support vector machine and Otsu's method. This method automatically adjusted the classification hyperplane that was calculated using linear SVM and required minimum training and time. The segmentation error varied from 3% to 25% for the fixed SVM, while the adjustable SVM achieved consistent and accurate results for each training set with the segmentation error of less than 2%. Tong et al (2013) used machine vision for the estimate quality of seeds of tomato, cucumber, aubergine, and pepper based on leaf area. In this work, a decision method and a methodology were developed for the watershed segmentation of overlapping leaf (OL) images. Relative identification accuracy of seedling quality was 98.6%, 96.4%, 98.6%, and 95.2% for tomato, cucumber, aubergine, and pepper, respectively. Sabzi et al (2013) studied mass modeling of Bam orange with ANFIS and linear regression methods for using in machine vision. ANFIS and linear regression models were employed to predict the mass based on perimeter and width/length value as inputs. The coefficient of determination (R^2), sum square error (SSE) and mean square error (MSE) for ANFIS and linear regression were 0.948, 405.7 and 13.99 and 0.919, 2246.43 and 23.159, respectively. Shin et al (2012) studied citrus mass and size estimation during postharvest processing using a logistic classification model and a watershed algorithm. In this study, a mass calibration process was conducted and fruit mass was estimated, which turned out to be reasonably good. The highest coefficient of determination (R^2) between the measured and estimated fruit mass was 0.945 and the root mean square error was 116.1 kg. Zheng et al (2010) conducted a study on developing an online method for quality evaluation and classification of some chlorophyll containing fruits in packing lines.

Khojastehnazhand et al (2009) conducted a study on axi-symmetrical agricultural products to compute surface area and volume using machine vision and image processing. Rashidi et al (2009) investigated cantaloupe fruits and determined their volume using water displacement and image processing methods. Koc (2007) used image processing to determine the volume of watermelons. Xing et al (2005) detected bruises on Golden Delicious apples using hyper spectral imaging with multiple wavebands. Leemans et al (2004) presented a real time grading method of apples based on features extracted from defects. Also, Lu (2003) presented a method for detecting bruises on apples using near-infrared hyperspectral imaging.

Sabliov et al (2002) applied an image processing algorithm to determine surface area and volume of axi-symmetric agricultural products. No report on the application of adaptive neuro-fuzzy inference system for mass modeling apple fruits has been documented. Nowadays, using such computerized grading systems necessities the research in this regard. Therefore, the aim of the present study is to offer a full automatic grading system for Emperor Apple with low error percentage using ANFIS coupled with machine vision technique.

2. Material and Methods

2.1. Samples

The Emperor Apple (Figure 1), a variety planted in Iran, was obtained from Kermanshah, Iran (longitude: 7.03 °E; latitude: 4.22 °N) and 100 samples were randomly selected. These apples were transported to Physical Laboratory, Faculty of Agriculture Engineering, Razi University, Kermanshah, Iran. All the tests were carried out on two days. The fruit mass was determined by an electronic balance with the accuracy of 0.01 g.

2.2. Work algorithm

This study performed based on off line method. There are several stages in this method, 1- design and development of imaging chamber 2- determination of the best condition for imaging, 3- development of a program in MATLAB to extract several features from apple, and 4- development of mass prediction model of apple based on ANFIS, linear and nonlinear regression models.

2.2.1. Image acquisition system

Machine vision system (Figure 2) is a combination of a 100 cm × 100 cm × 100 cm chamber, an illumination system installed around the chamber, a color video camera, a color grabber, and a personal computer (PC) equipped with MATLAB (ver. R20011a) and Microsoft Excel (ver. 2013) programs. The illumination system consisted of three type lamps: Fluorescent, Tungsten, and LED. There was a Dimmer to adjust the light intensity. The best image acquisition conditions and background were selected using the algorithm developed in MATLAB software.

Figure 1- Image sample of Emperor Apples

Şekil 1- Örnek Emperor Elma görüntüsü

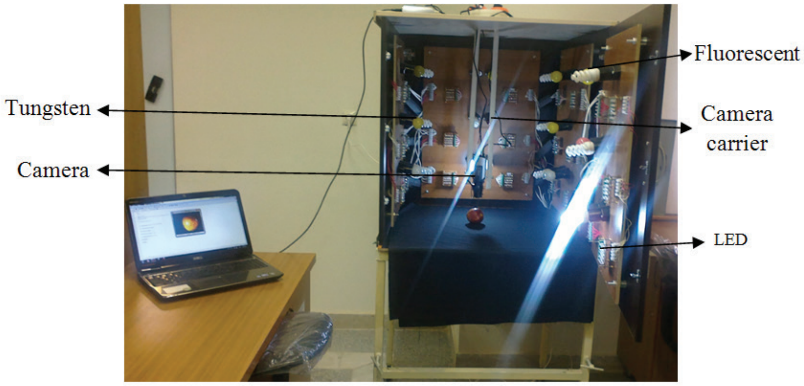

Figure 2- Special image acquisition of the chamber

Şekil 2- Özel görüntü odası

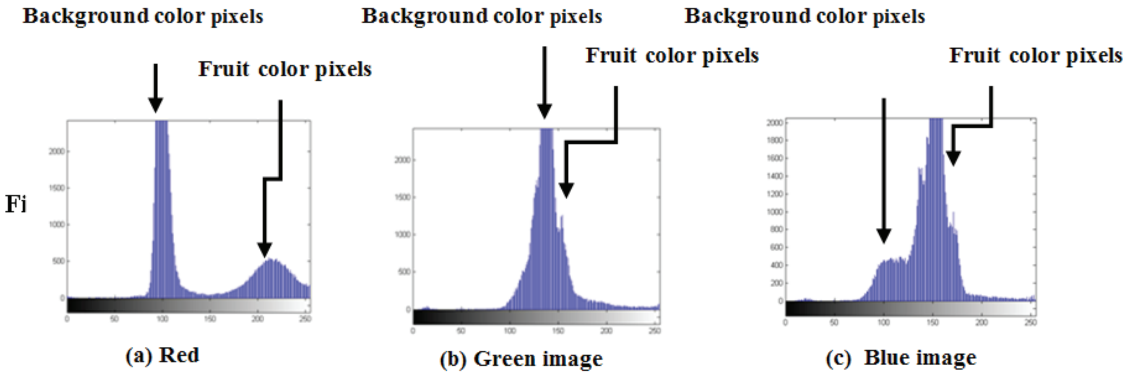

Figure 3- Image segmentation

Şekil 3- Görüntü ayırma

2.2.2. Determination of the best condition for imaging

At first stage, the stored images were recalled to get the best condition of photography. These images were converted into blue, red, and green values to draw the histogram. The best background and separation threshold were selected using the drawn histogram (Figure 3). Figure 3 shows the separated RGB image in green, blue, and red images. Peaks from left to right were the maximum frequency count of the color pixels of apple and background, respectively. Based on the distance between the apple and background pixel values, the red image was selected. At the second stage, diameter, area, center of mass, roughness, RGB and fruit entropy were determined. Edges were detected using canny and laplacian filters. Also, canny and laplacian filters were used for noise removal. Canny filter: By this method, edges are diagnosed with local maximum gradient f(x, y). Gradient is calculated using a derivative of Gaussian filter. In this method, two thresholds are used to identify strong and weak edges. Laplacian filter: In this method, edges are diagnosed after filtering f(x, y) using a Gaussian filter (Gonzalez et al 2004). The camera resolution was set at 352 × 288. Fluorescent lamp with the light intensity of 289.7l was selected. The distance between surface of the measurement table and the camera was 10 cm. At the third stage, the images were taken from 100 samples and the algorithms developed in MATLAB were used to measure 14 parameters including area, eccentricity, perimeter, length/area, blue value, green value, red value, width, contrast, entropy, wide/area, wide/length, roughness and length, which were then transferred to Excel.

2.3. Adaptive fuzzy neural network

ANFIS is a fuzzy inference system implemented in the framework of an adaptive fuzzy neural network. Sivasankaran et al (2011) argued that ANFIS can construct input–output data pairs using a hybrid learning procedure. This combination merges the advantages of fuzzy systems and neural networks. The main target of ANFIS is to find a model which can accurately simulate the inputs with the outputs. Rezaei et al (2012) argued that an ANFIS is used to map input characteristics to input membership functions, input membership function to a set of TSK type fuzzy if-then rules, rules to a set of output characteristics, output characteristics to output membership functions, and output membership function to a single-valued output or a decision associated with the output.

2.4. Statistical analyses

Model performance was examined using some statistic parameters such as mean squared error (MSE), sum squared error (SSE), and coefficient of determination (R^2), as shown below:

$$R^2 = 1 - \left\{\frac{\sum_{k=1}^{n}(X_k - X_0)^2}{\sum_{k=1}^{n}(X_k - X_m)^2}\right\} \quad (1)$$

$$X_m = \frac{1}{n}\sum_{k=1}^{n} X_k \quad (2)$$

$$MSE = \frac{1}{n}\sum_{k=1}^{n}(X_k - X_0)^2 \quad (3)$$

$$SSE = \sum_{k=1}^{n}(X_k - \overline{X_0})^2 \quad (4)$$

Where; Xs is the actual values; Xo is the forecast values; $\overline{X_0}$ is the average of experimental values; X_m is the mean of the actual values; n is the number of forecasts. These parameters evaluate the agreement between the actual and forecast values (Naderloo et al 2012).

3. Results and Discussion

3.1. Mass modeling of Emperor Apples

After extracting the 14 feature from apple, several models obtained using different inputs that among the models, seven models shown in Table 1, 2 and 3 were the best models. Specifications of ANFIS, linear and nonlinear regression models are presented in Tables 1, 2 and 3. The models were compared with three parameters of , SSE, and MSE. In the best model for ANFIS, linear and nonlinear regression, R^2, SSE, and MSE were 0.990, 276.58, 13.17, 0.856, 15980.96, 166.47 and 0.791, 24512.16, 255.35 respectively. In ANFIS method, to construct the models, five adjustments of membership function input, membership function number of input, membership function number of output, optimization method, and epoch number performed. The model gives acceptable results if all adjustments do accurately. Table1 shows that the models with two or three inputs had better results than one input model. When one input is used for model, prediction of output is relative to this input absolutely, but when two or rather than one input are used, prediction of output relative to combination of inputs. So, when one of the inputs was noisy, the model with several inputs had less error than the model with one input. Since ANFIS used nonlinear model and linear regression used linear model for modeling, ANFIS could cover more data than linear regression method and thus provide better results. In table 3 seven nonlinear equations of inputs and output had given. Nonlinear equations in SPSS have some limitation. In SPSS program, we must propose nonlinear equation, then parameters are initialized. So, achieving nonlinear equations in SPSS program is done based on trial and error. For this reason, this method has worse results than the other two methods. Figure 4 and 5 depicts the result of the regression analysis for ANFIS and linear regression. Tables 1, 2 and 3 show that ANFIS model was more accurate than the linear regression model and could precisely predict the mass of the apples. So, image processing along with ANFIS model can be used to launch an automatic mass-based grading system with low error percentage.

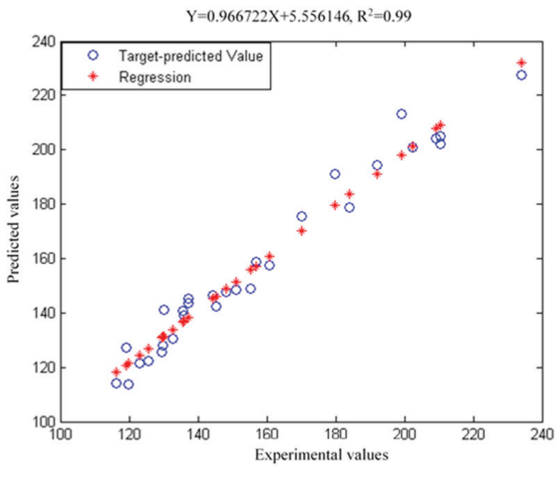

Figure 4- The comparison of experimental and ANFIS predicted values

Şekil 4- Deneysel ve ANFIS tahmin değerlerinin karşılaştırılması

Table 1- Summary of properties from some ANFIS models for Emperor Apple different types of inputs

Çizelge 1- Farklı Emperor Elması girdileri için ANFIS modelinde bazı özellikler

No	*MF input*	*MF number*	*Epoch number*	*MF output*	*input 1*	*Input2*	*Input3*	*R^2*	*SSE*	*MSE*
1	Gauss2mf	3 3 3	1500	constant	Width	Length	Perimeter	0.990	276.58	13.17
2	trimf	3 3 3	30	constant	roughness	Eccentricit	Perimeter	0.976	484.02	20.17
3	trimf	3 3 3	20	constant	entropy	Area	Width	0.964	820.41	31.55
4	gbellmf	5 5 5	50	linear	Length	Perimeter	entropy	0.875	4001.46	133.38
5	trimf	5 5 5	3	constant	Area	Length	Width	0.875	3893.24	129.77
6	pimf	3 3 3	150	linear	entropy	Contrast	roughness	0.852	3684.61	122.82
7	dsigmf	5 5 5	250	constant	Perimeter	entropy	R	0.50	9650.06	321.47

Table 2- Summary of properties from some linear regression models for Emperor Apple different types of inputs

Çizelge- Farklı Emperor Elması girdileri için doğrusal regresyon modelinde bazı özellikler

No	*Input1*	*Input2*	*Input3*	*Regression equation*		*SSE*	*MSE*
1	Width	Length	Perimeter	M= 0.029 W + 0.629 L + 0.705 P -123.95	0.746	30758.6	320.402
2	Roughness	Eccentricit	Perimeter	M= 0.059 r-7.003 E + 339.38 P- 174.37	0.856	15980.96	166.47
3	Entropy	Area	Width	M= 0.15 e + 0.003 A + 0.004 W-27.87	0.736	30549.16	318.22
4	Length	Perimeter	Entropy	M= 0.007 L + 0.036 P + 0.943 e-145.62	0.846	16987.4	176.95
5	Area	Length	Width	M= 0.725 A + 0.824 L + .000 W-136.48	0.844	16510.4	171.98
6	Entropy	Contrast	Roughness	M= 352.8 e + 209.6 C + 0.004 r-210.71	0.803	22806.95	237.57
7	Perimeter	Entropy	R	M= -0.051 P + 0.021 e + 0.035 R-124.96	0.799	20547.17	214.04

A, area; L, length; W, width; P, perimeter; e, entropy; C, contrast; r, roughness; E, eccentricity; R, red value

Table 3- Summary of properties from some nonlinear regression models for Emperor Apple different types of inputs

Çizelge 3- Farklı Emperor Elması girdileri için doğrusal olmayan regresyon modelinde bazı özellikler

No	*Input 1*	*Input 2*	*Input 3*	*Regression equation*		*SSE*	*MSE*
1	Width	Length	Perimeter	M= 5×10^{-18}ln(L) + 16.505ln(P) + ln(1×10^{-8})	0.169	88628.3	923.192
2	Roughness	Eccentric-ity	Perimeter	M= 31.036ln(r) + 293.28 ln(P) + ln(0.004)	0.791	24512.16	255.35
3	Entropy	Area	Width	M= 16.42ln(A) + ln(1.25×10^{-8})	0.151	101726.3	1059.65
4	Length	Perimeter	Entropy	M= 7.47ln(P) + 22.74ln(e) + ln(1.08×10^{-8})	0.165	92426.35	962.77
5	Area	Length	Width	M= 16.52ln(W) + ln(9.94×10^{-8})	0.169	88617.2	923.11
6	Entropy	Contrast	Roughness	M= 307.2ln(e) + 12.7ln(C) + 26.5ln(r) + ln(002)	0.678	40601.3	422.92

A, area; L, length; W, width; P, perimeter; T, entropy; C, contrast; r, roughness; E, eccentricity; R, red value

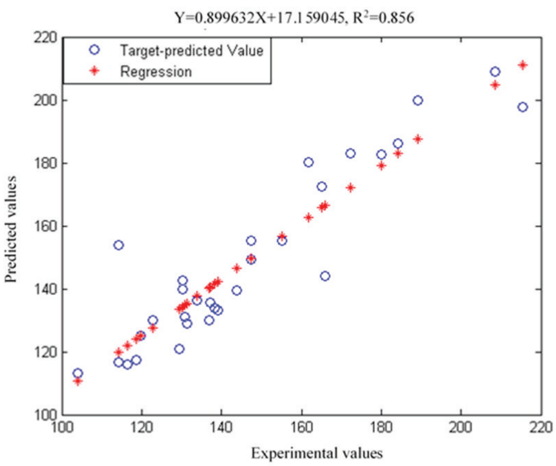

Figure 5- The comparison of experimental and linear regression predicted values

Şekil 5- Deneysel ve doğrusal regresyon tahmin değerlerinin karşılaştırılması

3.2. Adaptive fuzzy neural network analyses

The number of inputs and type inference system are shown in Figure 6. The model had three inputs (width, length, and perimeter) and one output (mass). Sugeno-type fuzzy inference system was used in the mass modeling of Emperor Apples. The relationship between training error and number of epochs in ANFIS model is shown in Figure 7. According to this figure, error decreased as epochs raised and finally it was leveled off (Naderloo et al 2012). Figure 6 presents the architecture of adaptive neuro-fuzzy inference system to predict the mass of Emperor Apples. Figure 8 demonstrates that the model had3 inputs, 1 output, and 27 rules. Figure 9 shows the initial Gaussian membership functions of the three appearance parameters. Membership function is a curve that maps each point of the input space into a membership value between 0 and 1. Figure 10 shows the reasoning procedure for the first order Sugeno fuzzy model. Since each rule has a crisp output, the overall output is obtained via a weighted average, thus avoiding the time consuming process (Taylan & Karagozoglu 2009). Input parameters of the considered ANFIS were width, length, and perimeter and the output was mass. Figure11 represent the change in the mass of Emperor Apples based on (a): length-perimeter, and (b): perimeter-width. It can be clearly seen in Figure 11(a) and (b) that impacts of length and width were larger than perimeter. Figure 12 shows the Mosaic mapping of width and length for mass modeling of Emperor Apples; the impact of width was more than length.

3.3. Grading system proposal

A grading system was shown in Figure 13. Emperor Apples with different sizes were placed on the conveyor belt and the camera took images from them. The images were then transferred to the computer to be analyzed by an algorithm written in MATLAB. After the analysis, the fruits are divided into three groups of small, medium, and large (Table 4). Three lines were built to transmit apples with different sizes (small, medium and large) to different parts of the package. This grading layout can be designed and fabricated for the packaging apple in relevant industries.

Table 4- Mean and standard deviation of groups

Çizelge 4- Grupların ortalama ve standart sapmaları

Statistical parameters	*Group*		
	1	*2*	*3*
Mean	113.38	145.82	198.84
Standard deviation	12.02	12.93	15.07

4. Conclusions

There are several methods for mass-based sorting such as indirect, mechanical, and electrical methods. If analysis of the data that are extracted using image processing from the fruit is done using ANFIS, mass model has a low error percentage; so, an indirect sorting system can be designed. In this research, the potential of ANFIS model for estimating Emperor Apple was investigated and compared with the well-known statistical method of linear regression technique in SPSS software.

1- For developing ANFIS models, 70% experimental data (randomly selected) were

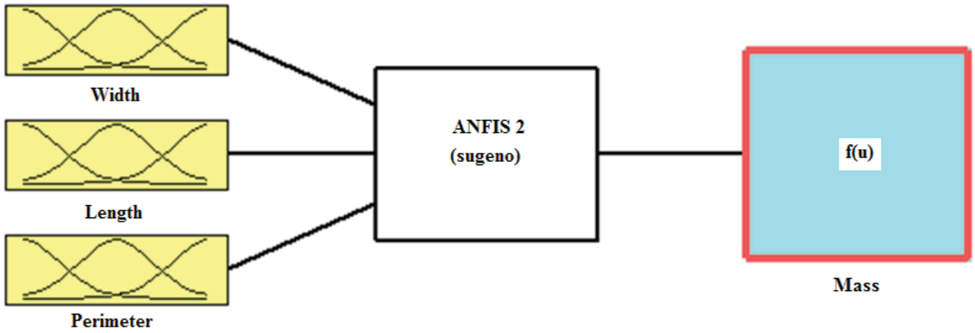

Figure 6- Structure of fuzzy inference system (FIS)

Şekil 6- Bulanık mantık arayüz sisteminin yapısı

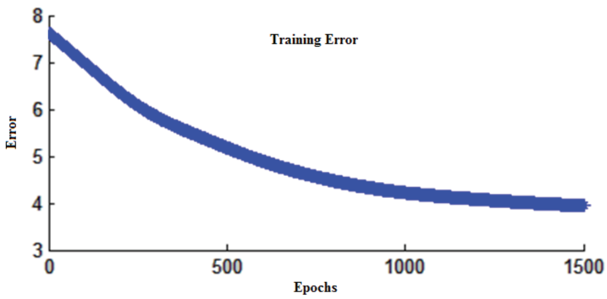

Figure 7- Relationship between training error and the number of epochs in ANFIS

Şekil 7- Eğitim hataları ve ANFIS evreleri arasındaki ilişki

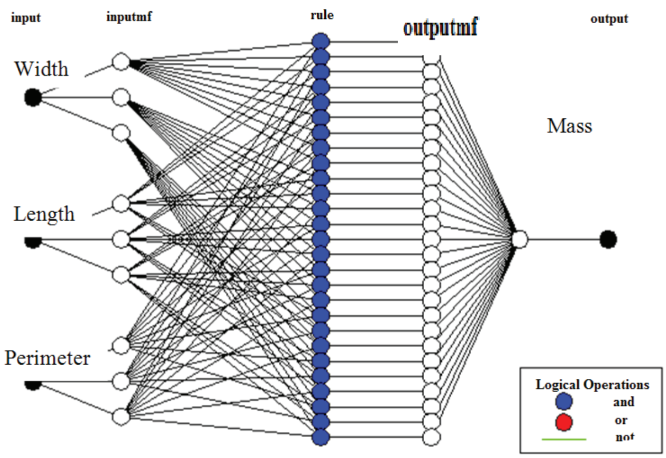

Figure 8- Structure of the proposed ANFIS model to predict the mass of Emperor Apples

Şekil 8- Emperor elmalarında ağırlık tahminleri için önerilen ANFIS modelinin yapısı

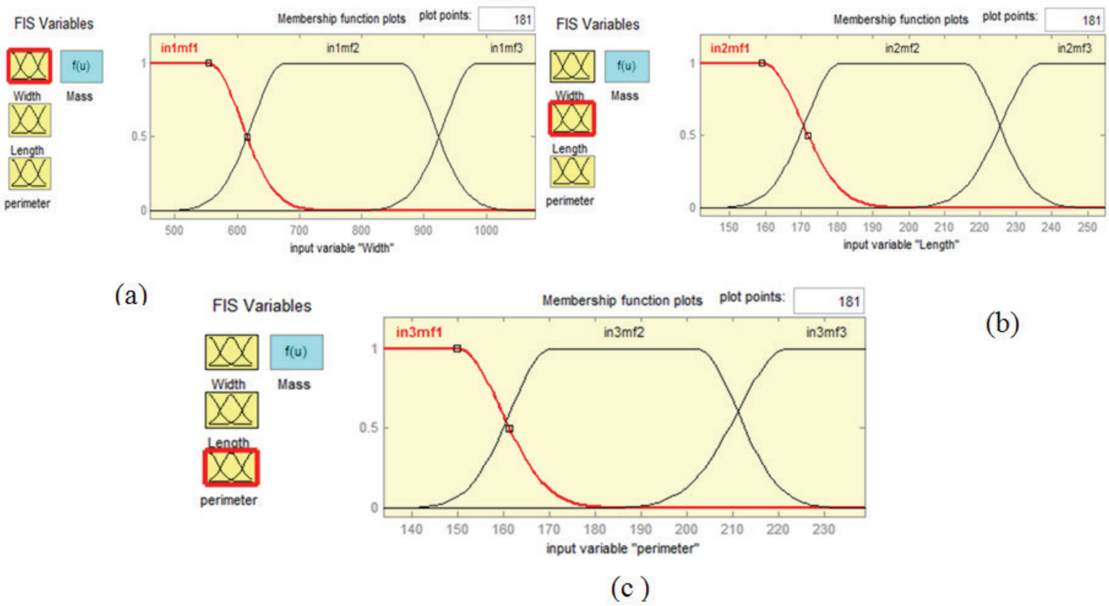

Figure 9- Membership functions of inputs (a), width; (b), length and (c), perimeter

Şekil 9- Girişlerin üyelik fonksiyonları (a), genişlik; (b), uzunluk ve (c), çevre

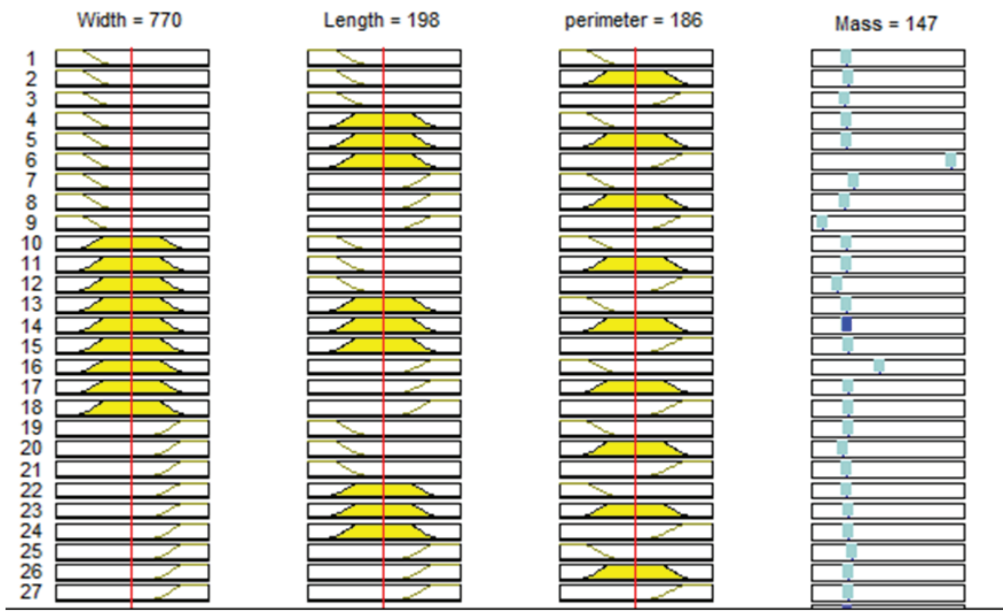

Figure 10- Fuzzy reasoning procedure for Sugeno model for mass assessment of Emperor Apples

Şekil 10- Emperor Elması ağırlık değerlendirmesi çin Sugeno modelinin bulanık sonuç prosedürü

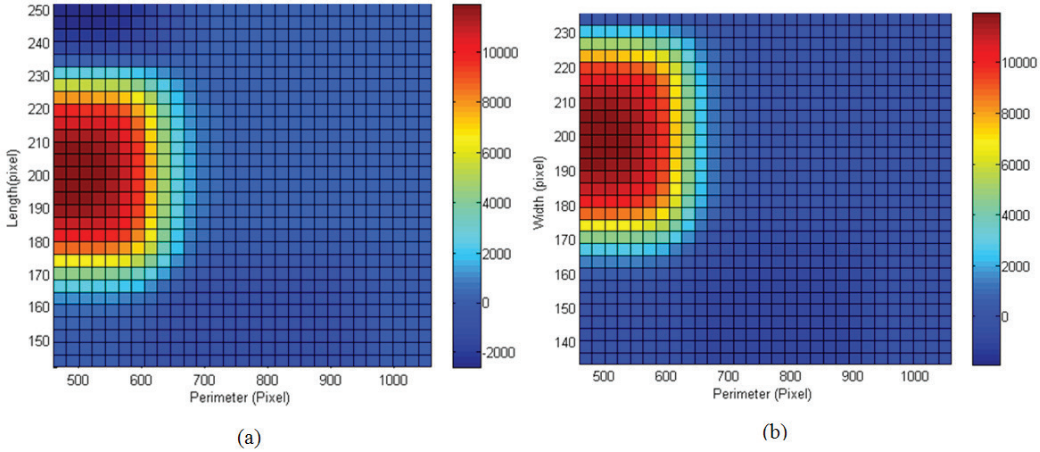

Figure 11- Mosaic mapping of (a) length, perimeter (b) width, perimeter for mass modeling of Emperor Apples

Figure 11- Emperor Elması çevre modeli için (a), uzunluk; çevre genişliği (b) mozaik haritası

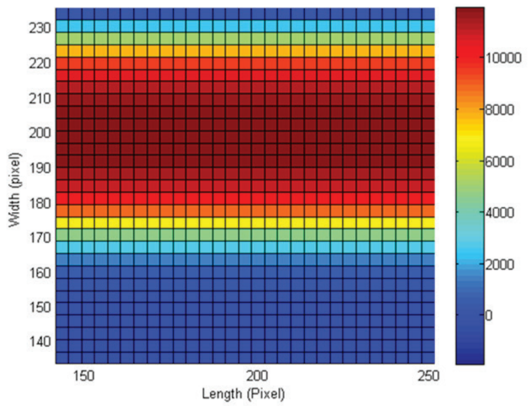

Figure 12- Mosaic mapping of width and length for mass modeling of Emperor Apples

Şekil 12- Emperor Elması modeli için uzunluk ve genişlik mozaik haritası

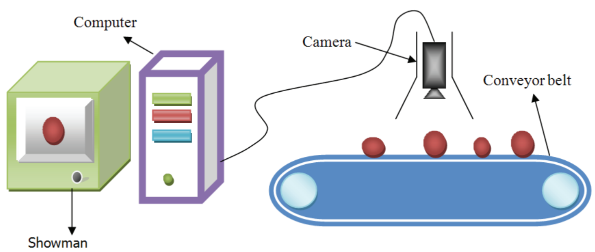

Figure 13- Layout of computer mediated fruit sorting system

Şekil 13- Bilgisayar ortamlı meyve sınıflandırma sistemi used for training and 30% (the residual data) were applied for testing the models.

2- For developing ANFIS model, different learning algorithms with different epochs were experimented to define the model which had the best potential of ability estimation to predict the experimental results.

3- The best correlation was found through three inputs (length, perimeter, and weitgh).

4- After finding the best ANFIS model, results of ANFIS and SPSS were compared.

5- For comparing ANFIS and SPSS, determination coefficient (R^2), SSE, and MSE statistics were used as the evaluation criteria.

6- In the best model for ANFIS and SPSS, R^2, SSE, and MSE were 0.990, 276.58, 13.17 and 0.746, 30758.6, 320.402, respectively.

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