Mass and volume determination of orange fruit using ultrasonic sensors

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Abstract

In this study, an electronic system was built to determine the mass and volume of orange fruits from their dimensions using ultrasonic sensors. The system hardware parts include a metal box, three ultrasonic sensors, a load-cell sensor, an Arduino board, a memory card module, a voltage converter, a keypad, a display and a power adapter. A computer program was written to obtain data from ultrasonic sensors and determine the mass and volume of fruits using regression relationships in Arduino software. 100 samples of orange fruits (Dezful local variety) were picked randomly from a garden and various measurements were done to determine the main physical properties of fruits including three dimensions, mass (M), and volume (V). The system output values for mass and volume of orange fruits with their actual values had no significant difference at 1% probability level. The root mean square error (RMSE) in determining the oranges mass and volume by the system were 9.02 g and 10.90 cm^3, respectively. In general, the proposed system performance was acceptable and it can be used for determining the mass and volume of orange fruits.

Key words: Electronic system, Hardware parts, Orange Fruit, Regression modelling, Volume and mass determination.

Introduction

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A large amount of orange fruits (*Citrus sinensis*) produced in Iran are lost (15-20%) due to lack of proper processing and storage conditions (Ahmadi *et al.*, 2020). While, it is possible to prevent the waste of this useful crop with suitable grading, packaging, and storage. Fruits can be graded based on various parameters such as size, colour, volume, and mass (Vivek Venkatesh *et al.*, 2015). The speed of automatic machines grading is faster than manual grading. High cost of the automatic machines is the main obstacle to use them (Dağtekin and Beyaz, 2017). Therefore, using appropriate techniques for cheap and rapid measurement of fruits mass and volume can play an important role in developing automatic grading systems and reducing orange fruits losses (Mir-Ahmadi *et al.*, 2016).

Various methods such as water displacement method (WDM), digital scales, density grading tubes, aerial comparison pycnometer, and radiation have been used to determine the volume and mass of agricultural products (Mohsenin, 1986; Kachariya *et al.*, 2015). These methods are usually time consuming and cannot be done automatically. Today, some systems equipped with electronic tools are used for the rapid weighing of agricultural products (Mir-Ahmadi *et al.*, 2016). Also, indirect and non-destructive methods, and using machine vision and various sensors have been considered by many researchers to determine the mass and volume of agricultural products (Concha-Meyer *et al.*, 2018; Yildiz *et al.*, 2019). According to the literatures, the image processing technique is effective for grading of the citrus fruits (Omid *et al.*, 2010; Fellegari and Navid, 2011; Raj Gokul *et al.*, 2015) and can be considered as a potential replacement to manual sorting (Vivek Venkatesh *et al.*, 2015); But the vision systems are very expensive, complex, and do not work in every lighting conditions. So, developing new techniques for fruits volume estimation to overcome problems like cost and accuracy is essential (Kachariya *et al.*, 2015). Replacing vision cameras with ultrasonic sensors can reduce the cost of

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fruits grading system and lead to grading in various lighting conditions. The ultrasonic sensors are more useful for determining distance in different lighting conditions compared to vision sensors (Dağtekin and Beyaz, 2017).

The objective of this study was to use electronic system that can determine the mass and volume of citrus fruits such as oranges from their dimensions using ultrasonic sensors, so that this technique can be used to determine the mass and volume of citrus fruits for online grading purposes.

Materials and Methods

In this study, 100 samples of orange fruits (Dezful local variety) were picked randomly from a garden and were transferred to the laboratory. Then, various measurements were done to determine the main physical properties of fruits including three dimensions, mass (M), and volume (V) at temperature of 17 to 22 °C and relative humidity of 53 to 73%. The oranges dimensions including height (h), width (w) and thickness (t) were determined in three directions perpendicular to each other using a calliper with 0.05 mm accuracy. The oranges mass was determined using a digital scale with accuracy of 0.01 g. The WDM was used to determine the volume of fruits (Mohsenin, 1986).

Two types of techniques (regression and ANN) were considered for modelling of the fruits mass and volume based on their dimensions. In the regression model (F(h,w,t)), three dimensions of the orange fruits were selected as independent variables and their mass or volume were selected as dependent variable (Masoudi and Rohani, 2017). Also, multilayer perceptron (MLP) neural network was used for modelling the mass and volume of orange fruits based of their dimensions (A(h, w, t)). The orange dimensions normalized values were selected as inputs and

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the orange mass or volume was selected as output of the ANN. Sigmoid function was selected as neurons activation function. Back-propagation with declining learning-rate factor (BDLRF) algorithm was used for the ANN training. Computer program of the ANN algorithm was developed in MATLAB version 8.1 software (Masoudi and Rohani, 2016).

The electronic system set up was built according to Figure 1 using CATIA v5, R2013 software (Dassault Systèmes, France). This system instantly determines the three geometric dimensions of orange fruit, including height (h), width (w), and thickness (t), and saves them in memory. The hardware components of this system include a metal case, three ultrasonic sensors, a load-cell sensor, an Arduino microcontroller board, a memory card module, a voltage converter, a keypad, an LCD, and a power adapter.

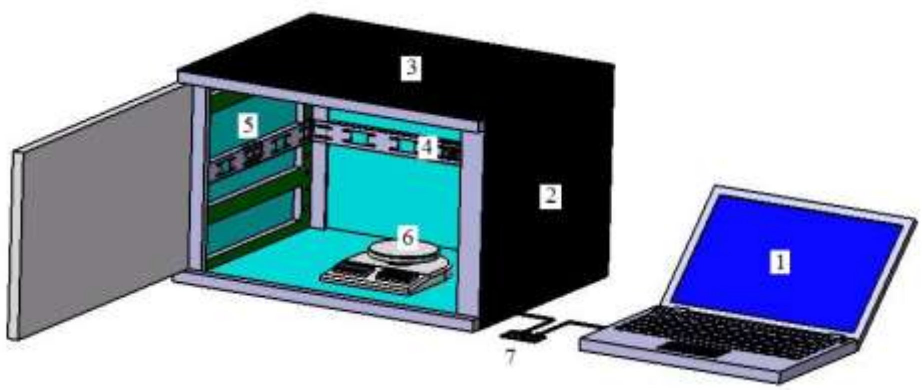

Fig.1. Electronic system set up to determine the mass and volume of orange fruits (1- Computer 2- Metal body 3- LCD display 4- Thickness sensor 5- Width sensor 6- load-cell sensor 7- Arduino board)

A Mega Arduino microcontroller board was used as the system processor (Figure 2-a). A memory card module (Arduino data logger shield) mounted on the Arduino board was used to save the data. A voltage converter module was also used to supply the required voltage to the

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sensors from the adapter. A 3×4 keypad and a 4×20 LCD were mounted on the top of metal case for settings and showing results (including three dimensions, mass, and volume of oranges).

(a) (b)

Fig.2. a) Arduino Mega board, and b) USS3 ultrasonic sensor

Three USS3 ultrasonic sensors (Best Technology, Japan) were used to determine dimensions of the orange fruit (Figure 2-b). Values of the internal parameters of this sensor were adjusted to detect objects at distances of 15 to 250 cm (Anonymous, 2008). An ultrasonic sensor was installed at top of the case to determine the fruit height, one on the right side of the case to determine the fruit width, and another at the back of case to determine the fruit thickness. Then, the analogue output of the sensors was connected to the A/D input of the Arduino board. Each sensor receives a reflection by sending a sound wave, and sends the fruit-sensor distance, as a DC voltage in its output, to the Arduino board. USS3 sensor output voltage in the analogue mode (V) is proportional to distance (d). The calibration coefficient, named DAC_value [cm], shows the distance in which the sensor output is 5 Volt. In this study, DAC_value was determined (=45.75 cm) and used to calculate distance using Equation 1. Also, sound speed (v in m/s) can be saved as an internal parameter of USS3 sensors according to the environment temperature (T in °C). This parameter was calculated for the laboratory temperature (= 22 °C) and saved as an internal parameter of the sensors using Equation 2 (Anonymous, 2008):

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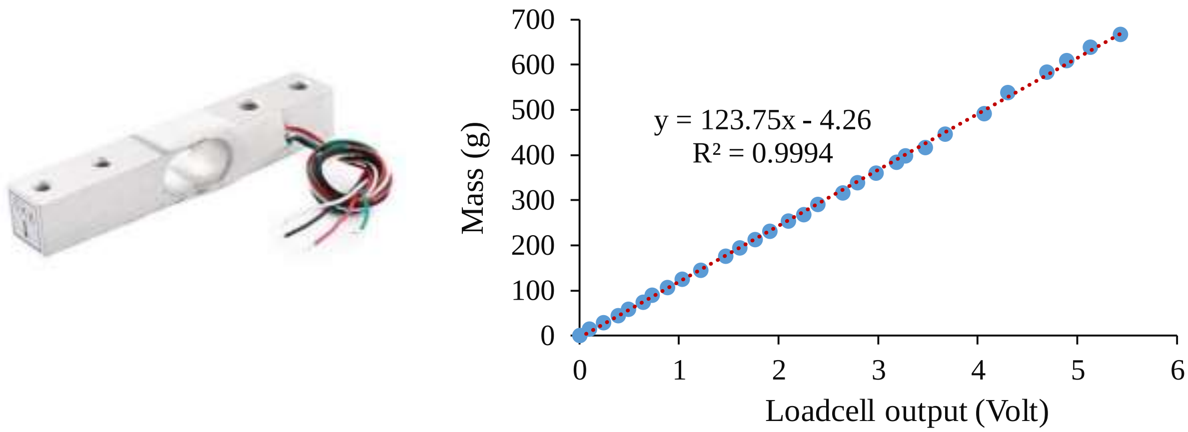
$$d = V \times DAC\_value / 5 \tag{1}$$

$$v = 331.5 + 0.605 \times T \tag{2}$$

An YZC-133 load-cell sensor with 5 kg capacity was used to get the fruits mass (Figure 3-a). An AD620 voltage amplifier module was used to amplify the output signals of the load-cell up to 4000 times. The load-cell calibration equation was obtained as shown in figure 3-b.



(a) (b)

Fig.3. a) YZC-133 Load-cell and b) Calibration graph and equation of the load-cell

A computer program was written using Arduino IDE version 1.8.9 to obtain data from the ultrasonic and load-cell sensors by the microcontroller, determine the required parameters (including orange mass and volume), and display and save them on the memory card. In the computer program, the relationships between three dimensions and fruit mass and volume were used to determine the fruit mass and volume obtained by regression modelling (Figure 4). While the Sync line of USS3 sensors was used, the sensors were activated at one-second intervals. Therefore, the sensors output were read with one-second distance between them. As a result, the signals interference was decreased. Also, a median filter was used in the program for deleting remained noises from all sensors outputs. The system performance was simulated in Proteus 8.13 software (Labcenter Electronics, England) as shown in Figure 5.

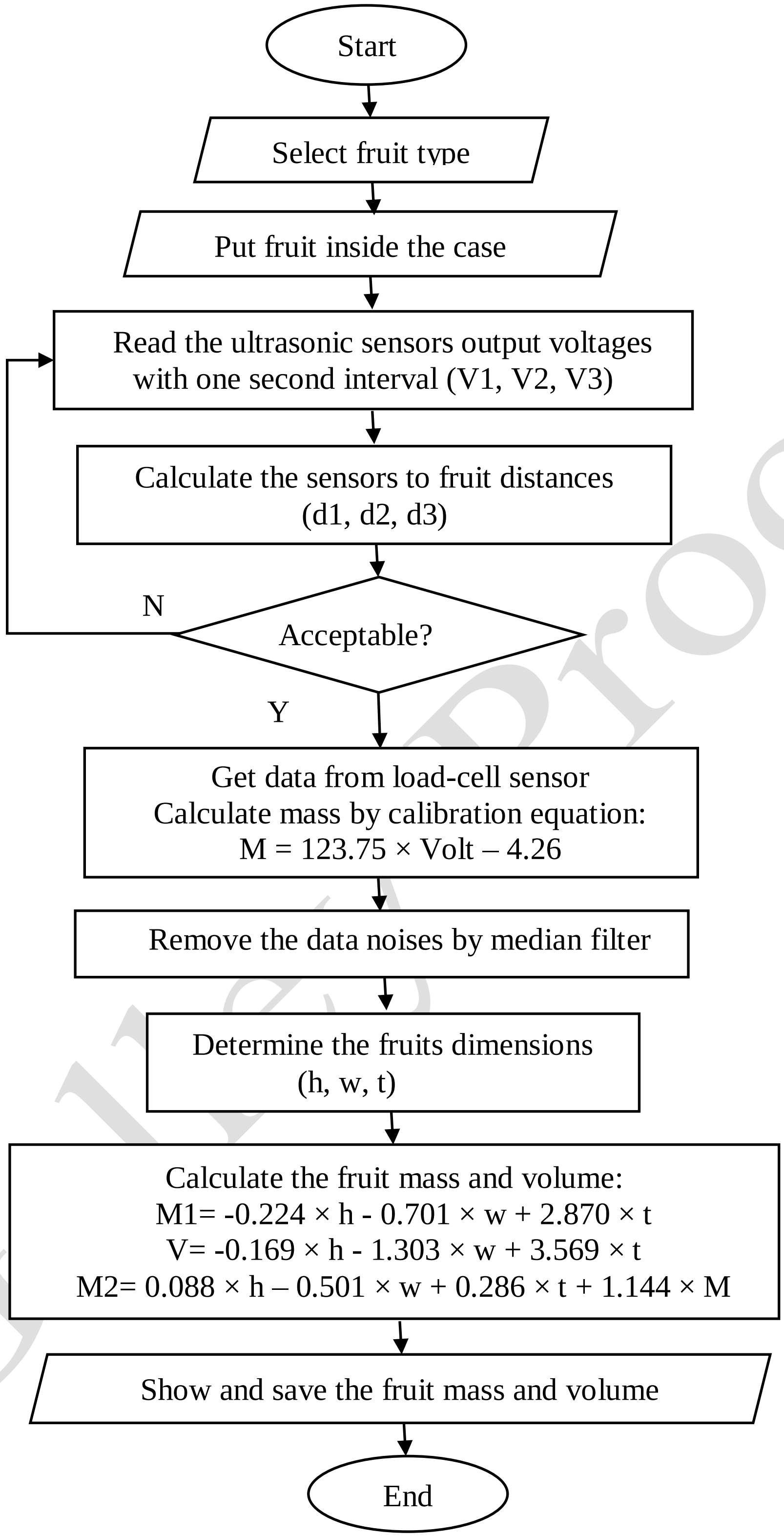


Fig.4. Steps for determining the orange mass and volume by the electronic system

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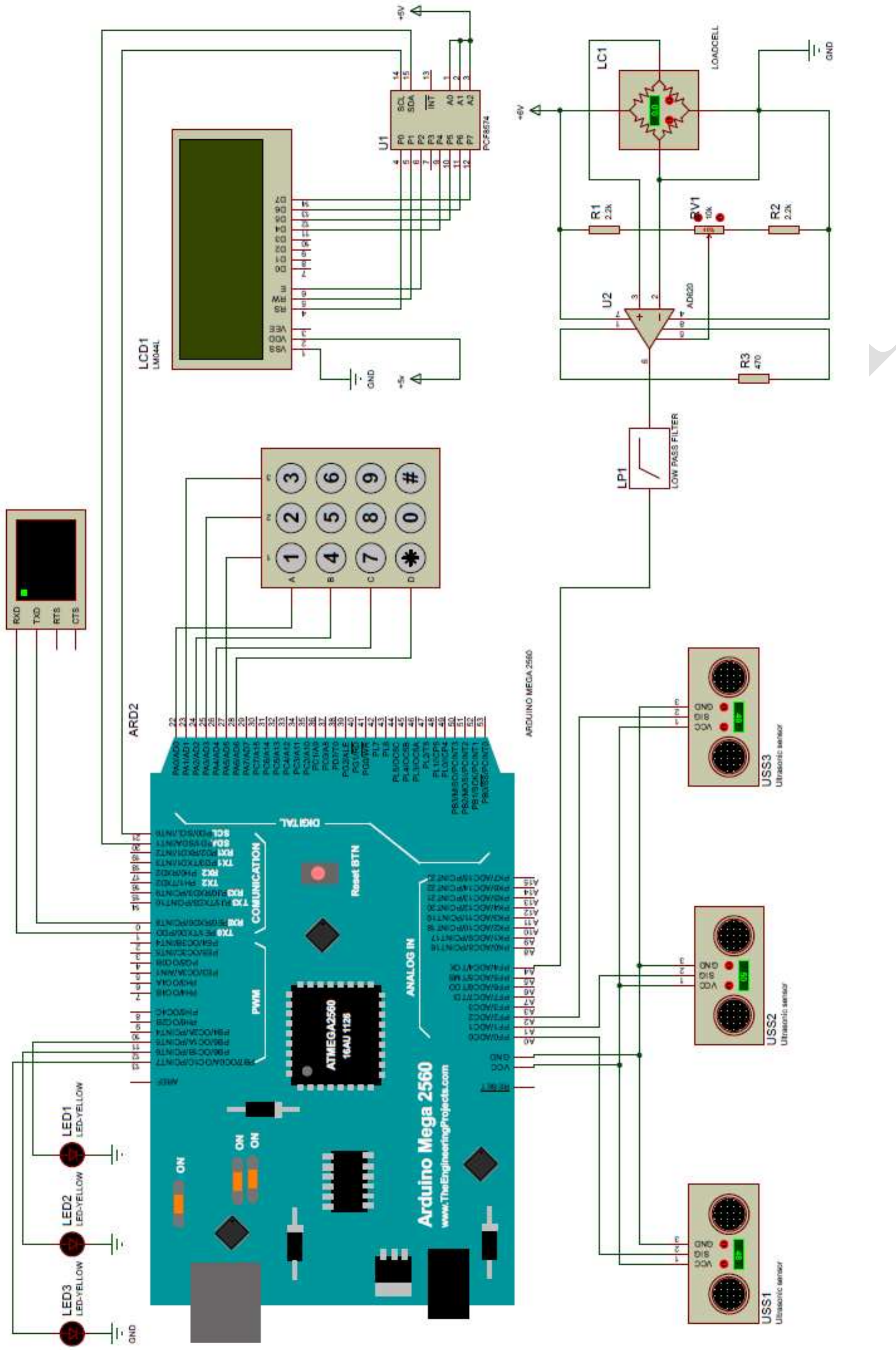

Fig.5. Electronic circuit of the system designed in Proteus software

To evaluate the performance of electronic system in determining the mass and volume of orange fruits, 50 samples (Concha-Meyer *et al.*, 2018) of the fresh orange fruit (Dezful local variety) were provided, and the actual values of their three dimensions, mass and volume were determined by a digital calliper, a digital scale (with an accuracy of 0.05 g), and WDM, respectively. Then, as shown in Figure 6, the three dimensions, mass and volume of all 50 fruits were measured using the proposed electronic system in four repetitions. Finally, two statistical criteria, i.e. root mean square error (RMSE) (Equation 3) and mean absolute percentage error (MAPE) (Equation 4) were used for the results evaluation. Comparison of the mean of real values with the system output values was performed at 1% probability level by paired Student t test using Excel 2013 software (Microsoft, USA) (Masoudi and Rohani, 2021).

$$RMSE = \sqrt{\frac{\sum_{i=1}^{n}(A_i - P_i)^2}{n}} \tag{3}$$

$$MAPE = \frac{\sum_{i=1}^{n}\left|\frac{A_i - P_i}{A_i}\right|}{n} \times 100 \tag{4}$$

Where A_i is the actual mass or volume of the fruit, P_i is the output value of the system, and n is the number of fruits.

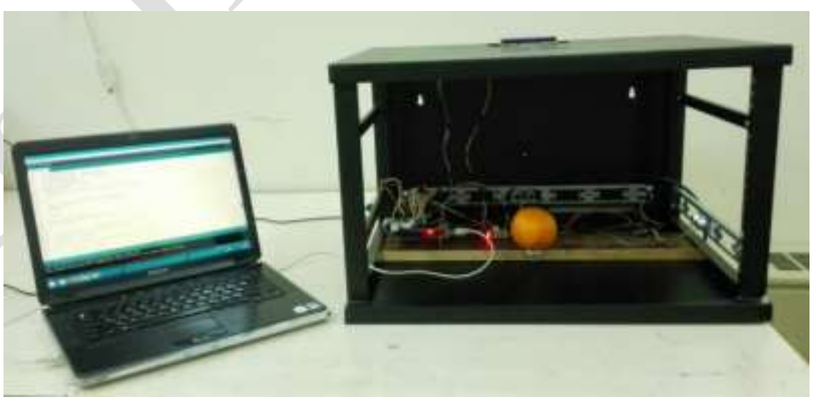

Fig.6. Practical tests to evaluate the performance of the built electronic system

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Results and discussion

Analysis of variance of the F(h,w,t) model showed that there was a significant relationship at 1% level between the mass or volume of oranges and three dimensions. The obtained regression equations for orange mass and volume estimation based on three dimensions are shown in Equations 5 and 6. The R^2 values show that these equations can justify 95.97% and 98.01% of changes in the orange mass and volume, respectively (Masoudi and Rohani, 2017)..

$$M = -188.30 + 0.600\,h + 1.899\,w + 2.583\,t \quad , \quad R^2 = 95.97\ \% \tag{5}$$

$$V = -252.30 + 1.703\,h + 2.246\,w + 2.317\,t \quad , \quad R^2 = 98.01\ \% \tag{6}$$

Also, in the ANN modelling, the results of statistical comparisons between the mean, variance, and distribution of the actual data and the predicted data showed that there was no significant difference between them and the minimum value of R^2 for the mass and volume in all three phases of the ANN was equal to 0.96. According to these results, the A(h, w, t) model could learn well the pattern of changes in the mass and volume of orange fruits using their dimensions (Masoudi and Rohani, 2016).

Finally, the two proposed models for estimating the mass and volume of orange fruits were compared with each other. According to the small values for RMSE and MAPE and the large value for EF indices, the prediction performance of A(h, w, t) model was better than the F(h, w, t) model. One-way analysis of variance was done for three set of data including the actual data, the predicted data by the F(h, w, t), and the predicted data by A(h, w, t). The results of mean comparison by LSD method for these three set of data showed that the difference between them were not significant at 1% probability level. So there was no difference between the two models statistically and any of the models could be used to estimate the orange mass or volume (Masoudi and Rohani, 2016, 2017). Since, the regression model implementation was easier and

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its running was faster than the ANN model in Arduino boards, so this model was used for final evaluation of the electronic system performance in this study.

The actual values of the physical characteristics for Dezful local variety of orange fruit along with the values measured by the system are given in Table 1. Low standard deviation (SD) and coefficient of variation (CV) of characteristics indicate the uniformity of fruit. Regression equations between the geometric dimensions of orange fruit with their actual mass and volume values were obtained according to Equations 7 to 9. Due to high R^2 of these relationships and since the regression equations in terms of three dimensions of oranges have good accuracy in determining the mass and volume of orange fruit (Masoudi and Rohani, 2016, 2017), these regression equations were used to evaluate the system performance. In practice, the volumes calculated by equations 8 and 9 were completely equal together. Therefore, the results mentioned below are correct for both of these equations.

$$M = -0.2243\,h - 0.7013\,w + 2.8703\,t \quad , \quad R^2 = 99.61\% \tag{7}$$

$$V = -0.1690\,h - 1.3027\,w + 3.5691\,t \quad , \quad R^2 = 99.54\% \tag{8}$$

$$V = 0.0876\,h - 0.5005\,w + 0.2859\,t + 1.1438\,M \quad , \quad R^2 = 99.97\% \tag{9}$$

The comparison of the actual geometric dimensions of the orange fruit (obtained from the practical experiments) with the measured dimensions by the electronic system is shown in Figure 7. Comparing the means with Student t-test showed no significant difference between the system output values and their real values for orange fruit height and width at 1% probability level. However, there was a significant difference between the actual thickness values and the system output at 5% probability level. Therefore, the system accuracy in determining the thickness was less than the other two dimensions. But, considering that there is no significant difference between the values of geometric mean diameters (GMD) in both methods at 1% level, it can be

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concluded that the electronic system performance in determining the geometric dimensions of orange fruit is acceptable.

Table 1- Physical characteristics of the orange fruits determined by the system

Physical characteristics	Average		SD		CV (%)	
	Actual value	System output	Actual value	System output	Actual value	System output
Height (mm)	59.34	59.14	2.62	2.11	4.42	3.57
Width (mm)	60.87	60.39	2.36	3.05	3.88	5.05
Thickness (mm)	60.17	58.97	2.38	2.83	3.96	4.81
GMD* (mm)	60.12	59.48	2.19	2.23	3.65	3.74
Mass (g)	116.48	113.64	11.84	6.55	10.17	5.77
Volume (cm^3)	125.15	121.79	13.54	7.59	10.82	6.23
Density (g cm-3)	0.93	0.93	0.02	0.01	1.70	0.99

* Geometric mean diameters

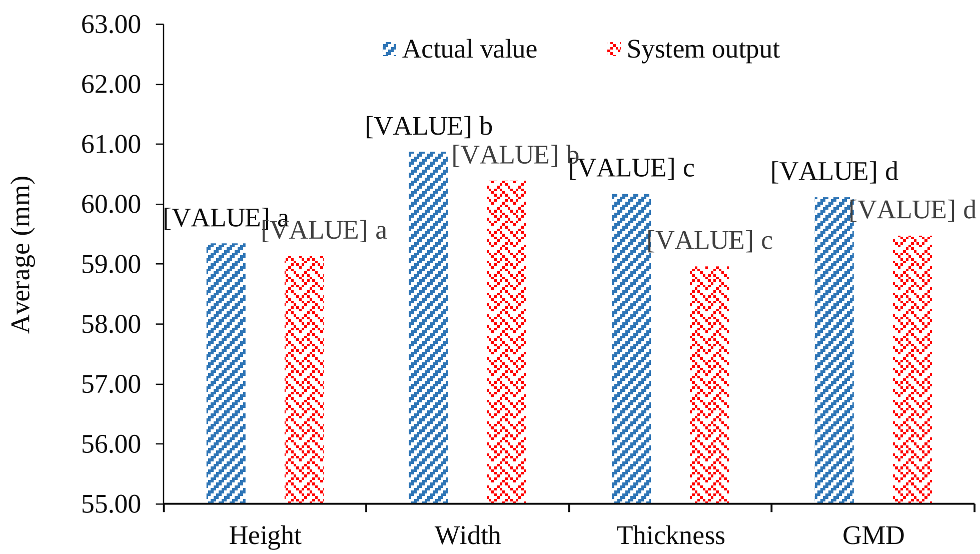

Fig.7. Comparison of the actual values of orange fruits geometric dimensions with the values measured by the electronic system

As shown in Figure 8, based on the Pearson's correlation coefficient values the actual and measured values for volume and mass of orange fruits were highly correlated. Also, the mean errors (RMSE) for determining the orange mass and volume by the system were 9.02 g and 10.90 cm^3, respectively, and the MAPE for determining the mass and volume of oranges by the system was 5.54 and 6.13%, respectively. These mean that the electronic system could determine the mass and volume of fruits with a minimum error that is acceptable for commercial uses.

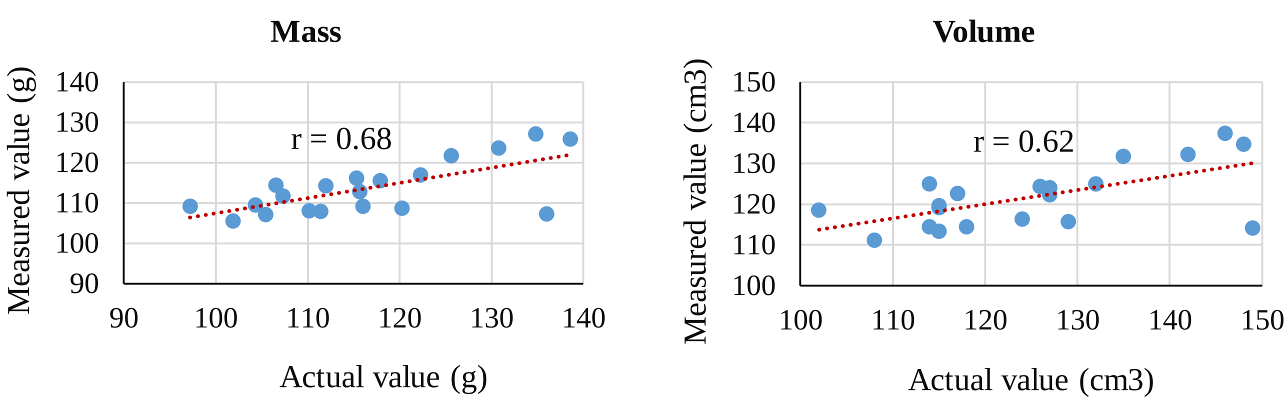

Fig.8. Correlation of actual and measured values for mass (left) and volume (right) of orange fruits

The student t-test showed no significant difference between the system output values for mass, volume and density of orange fruit with their actual values at 1% probability level. Comparison of the actual mass and volume of orange fruit (obtained from the practical experiments) with the values measured by the electronic system is shown in Figure 9. In the study of Omid *et al.* (2010), and Fellegari and Navid (2011), no significant difference was observed between the orange volume predicted by the image processing technique and the actual values of this parameter.

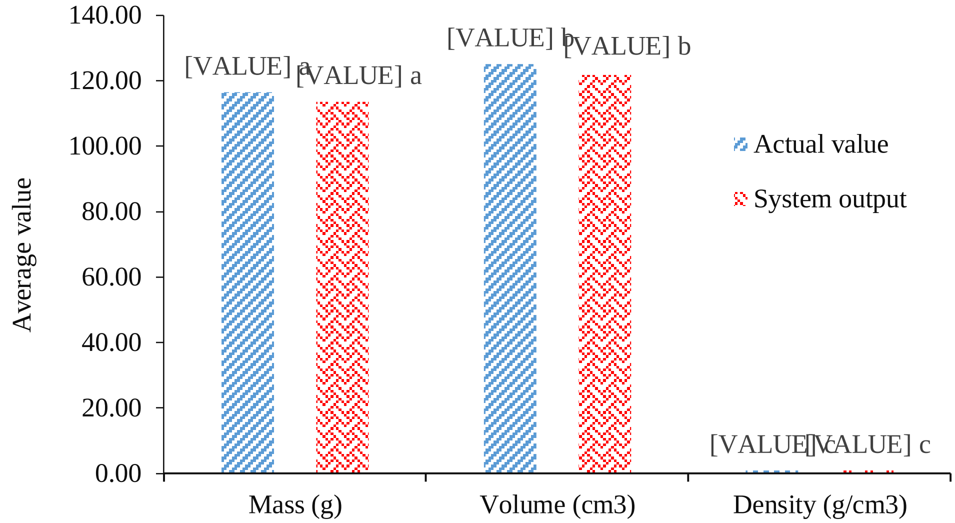

Fig.9. Comparison of the actual values of mass and volume of orange fruits with the values measured by the electronic system

According to these results, the electronic system performance in determining the mass and volume of orange fruit is acceptable. This system can be used to determine these two characteristics. The proposed system is a prototype and laboratory version. By this system, it is possible to estimate the volume of one fruit in 5 seconds, which will be 720 fruits per hour and will weigh between 80 and 100 kg. For 10 hours of work per day, about 1000 kg of fruits can be graded. Also, installing several grading lines in parallel can increase the grading capacity. Since volume determination by WDM takes about 1 minute time, so this system is more comfortable and about 12 times faster than WDM.

Conclusions

The applied system evaluation experiments, using regression equations, showed that the system performance in determining the orange fruit mass and volume is acceptable and can be used to determine these two characteristics. Since, the system can determine the volume of fruits

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with only three ultrasonic sensors, by removing the load-cell, the system production costs will decrease. For commercialization, regression equations to estimate the fruits volume from their dimensions for various fresh and un-fresh fruits with different moisture content should be extracted and added to the computer program of the system. The salient features of the presented system for online grading of fruit based on their volume are: less complex than vision systems, working in any lighting conditions, less cost, and ability to save the results.

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Declarations of interest: none

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تعیین جرم و حجم میوه پرتقال با استفاده از حسگرهای فراصوتی

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چکیده:

در این پژوهش یک سامانه الکترونیکی برای تعیین جرم و حجم میوه پرتقال با استفاده از حسگرهای فراصوتی ساخته شد. اجزاء سخت افزاری سامانه شامل بدنه فلزی، حسگرهای فراصوتی، حسگر نیرو، برد آردوینو، ماژول کارت حافظه، مبدل ولتاژ، صفحه کلید، نمایشگر و آداپتور برق می باشد. یک برنامه رایانه ای برای اخذ داده ها از حسگرهای فراصوتی و تعیین جرم و حجم پرتقال ها با کمک روابط

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رگرسیونی در نرم افزار آردوینو نوشته شد. ۱۰۰ نمونه از میوه پرتقال رقم محلی دزفول از یک باغ بصورت تصادفی چیده شد و آزمایشات مختلفی برای تعیین خواص فیزیکی آنها شامل ابعاد، جرم و حجم میوه انجام شد. مطابق نتایج ارزیابی سامانه، بین مقادیر خروجی سامانه با مقادیر واقعی جرم و حجم میوه های پرتقال رقم محلی دزفول اختلاف معنی داری در سطح احتمال یک درصد مشاهده نشد. مقادیر ریشه میانگین مربعات خطا (RMSE) در تعیین جرم و حجم پرتقال ها توسط سامانه به ترتیب برابر با ۹/۰۲ گرم و ۱۰/۹۰ سانتی مترمکعب بدست آمد. در مجموع، عملکرد سامانه ساخته شده قابل قبول بود و لذا می توان از آن برای تعیین جرم و حجم میوه های پرتقال استفاده نمود.

واژه های کلیدی: سامانه الکترونیکی، اجزاء سخت افزاری، میوه پرتقال، مدلسازی رگرسیونی، تعیین جرم و حجم.

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