Automatic Infrared-Based Volume and Mass Estimation System for Agricultural Products

Along with Major Geometrical Properties

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***Abstract*— Volume and mass estimation are two important factors in quality grading for agricultural products. Using novel automatic volume and estimation systems decreases the human error and saves significant amount of time in this process. Novel methods use color image (and some cases depth image) to estimate the volume and mass, but still there are considerable amount of error in irregular and non-symmetrical shaped products and they do not work properly in different distances from product. Proposed method uses Kinect version 2 sensor to fix this problem using produced depth images from infrared sensor. Totally 10 features out of color and depth images are extracted which volume and mass are just two of them. Also, proposed method works very well in pure darkness. Another mentionable feature is fast response in real time calculation. The final results show improvement in compare to traditional and novel methods.**

Keywords*— *Agricultural products grading; Automatic volume and mass estimation; Kinect Version 2; Depth image; Irregular and non-symmetrical shaped products; Real time calculation

I. Introduction

As demand increases, it lifts up the supply. With increasing health care and insurance, population increase which leads to need for more sources of food [1, 2]. As the paper is about volume and mass estimation of fruits and vegetable or agricultural products and these words are going to uses a lot, the word of 'product' or 'agricultural product' is going to use for this purpose in whole entire paper as it is not reasonable to use three words in each necessary definition (when it is necessary). In recent decades farming and distributing agricultural products are increases rapidly as main source of food, which have high profit for farm owners. This number of fruits and vegetables need perfect, precise and modern tools to plant, harvest, quality evaluation and packaging for export [3]. In quality evaluation part, product grading plays an important role in quality management. Volume and mass estimation are part of product grading process. Traditional volume estimation method like Water Displacement method (WD) [4] is so time consuming and damages the products. Also, it does not calculate exact amount of volume in agricultural products in different shapes (irregular and non-symmetrical) [2] and has higher error versus modern methods. It has to be mention that when high number of products are considered to calculate the volume, heavy machinery is needed which is not costly efficient. Traditional mass estimation method is called Digital Balance (DB) method. This method is time consuming and effects the freshness of the product.

Computer vision and image processing techniques had perfect impact in agricultural product processes from planting till packaging. One of the best impacts is in grading process. Automatic volume and mass estimation of the products is the most efficient among these processes. Agricultural product detection, recognition and classification [5-6, 35-36] has high of importance in agricultural industry. There are a mentionable novel and efficient computer vision-based techniques in agricultural product volume and mass estimation which most of them are color image-based techniques, not depth image based. Those methods are good and efficient but not enough in every distance and product shapes. Proposed method is based on RGB-D (Red Green Blue – Depth) images and it compared with traditional and novel techniques in same condition. Proposed method lifts up the existing methods to a level higher in precision, different distances and also in pure darkness aspects, as it uses infrared sensor. Here, Microsoft Kinect version 2 sensor [7, 8] is employed as the main sensor which is equipped with night vision technology based on infrared particles in decent quality and resolution.

In order to compare our method versus traditional volume and estimation methods, simulating traditional methods were necessary. Fig. 1 (a) shows WD method for estimating volume of a carrot sample. Also, Fig. 1 (b) shows simulated traditional mass estimation method for the same carrot sample.

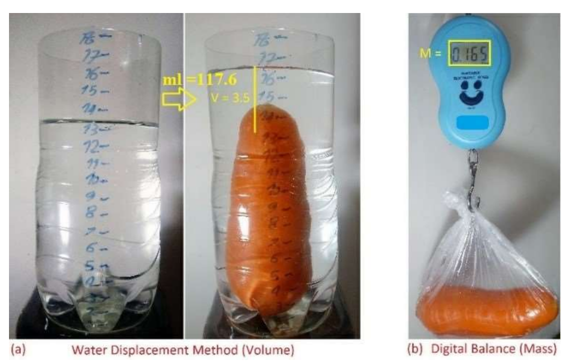

Fig. 1. (a) using traditional WD method on a carrot sample (volume) and (b) using traditional digital balance method for the same carrot (mass)

There are different depth sensors with different technologies but, Kinect is one of the most famous, low-cost and Time of Flight (TOF) [7, 8, 9] sensors available which is proper for both research purposes and in application. As the main tools for this research is Kinect V.2 sensor, Fig. 2 shows employed Kinect V.2 sensor's structure. The depth structure for one of the eggplant samples is shown along with color version of the same product in Fig. 3.

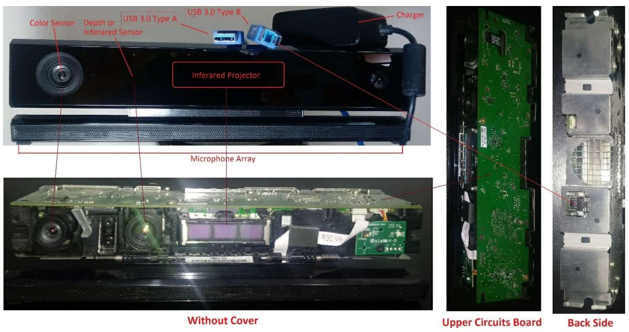

Fig. 2. Employed Kinect V.2 sensor in the research

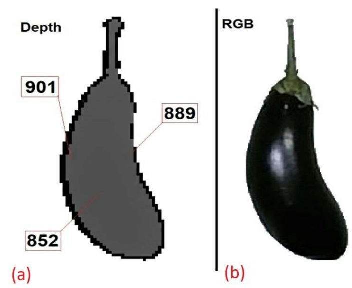

Fig. 3. (a) is the depth structure shown as an intensity channel of an eggplant vegetable. The smaller value means closer distance to the sensor and vice versa. (b) is the standard color (RGB) image of the same eggplant.

The paper is consisting of 5 main sections as follow. Section I is all about why it is worth to research and what is shortages and needs in this area. Also, the problems and general definition of existing methods to solve it and what is the weakness of those method and how proposed method's solution is going to fix it. Section II demonstrate all traditional and novel volume and mass estimation methods in details. Section III pays to the proposed method which is presented in this paper. Materials, evaluations and results shapes the section IV. Finally, conclusion. Discussion and suggestions for future works are describes in section V.

II. PRIOR RELATED RESEARCHES

As it mentioned in previews section, there are traditional volume and mass estimation methods available which are used for a long period of time and still are using in many countries. WD method for calculating the volume and DB for mass. But in order to decrease human error, increasing processing speed, saving more cash and human energy, preventing product damage and increasing the accuracy, it was needed for modern methods to be invented. In this section some of the most important, valuable and recent researches in automatic volume and mass estimation of agricultural products which are employed computer vision techniques will be explained.

One of the mentionable researches is Jana, Susovan and et al, effort to automatic volume and mass estimation of fruits and vegetables using ordinary smartphone color cameras in 2020 [2]. They used preprocessing techniques very well in the first step and finally employed 2-D polynomial approximation equation to achieve their goals. Also, their system works for irregular and non-axisymmetric products in specific distance from sensor. They validated their system by potato, tomato and citrus products with 77 samples in total. Their system did not support pure darkness situation and also in different distances which in this research this problem is fixed. They achieved 7.46%, 10.98% and 10.98% error for potato, citrus and tomato respectively.

Another mentionable research is Vivek Venkatesh, G., et al effort in 2015 [10]. They attempt to make a system for calculating volume and mass of Axis-Symmetric fruits using color sensors (single view). Their system does not support irregular and non-symmetrical shaped products. First, they extract the boundary counter and then categorized the fruit into circular and elliptical shapes. Volume is calculated based on the specific fruit in each experiment and mass is calculated based on the relationship between mass and volume. Also, they used four types of citruses in validation section (120 samples). It is mentionable that, Susovan and et al compared their method with Vivek Venkatesh, G., et al and traditional methods and achieved better results. Proposed method compares with both of the mentioned researches and the following research plus traditional methods in accuracy and speed aspects.

Another recent research which is used for comparison purposes is take placed in 2019 which, Mousavi, S.M.H. and Prasath, V.S employed Depth sensors (Kinect) in order to just estimate fruits weight [11]. They tested their system in different product distances of 0.8, 1.0, and 1.3 meters from sensor. Their system starts with pre-processing steps, and estimating the weight using average weight of the experimented product and its distance from sensor plus a constant and finally normalization of the final value into gram. They used 150 samples of Sweet Lemons (Citrus limetta), Sweet Peppers (Capsicum annuum), and Tomatoes (Solanum lycopersicum) for validation purposes. Their system is just for mass or weight and achieved recognition accuracy of 94.7 %. Although their system is not strong enough in result section but it is depth-based system which is admirable.

Another strong paper which released in 2019 was Nyalala, Innocent, et al work on estimating cherry tomato volume and mass using depth-based images acquired with Kinect sensor. They extracted features such as projected area, perimeter, eccentricity, major-axis length, minor-axis length, radial distance and surface area from 2-D and 3-D images and used different regression techniques to evaluate these extracted features and calculate the final Root Mean Square Error (RMSE) [19] error. Also, they captured from three different view of the cherry tomatoes [12]. Their system is very strong and amazing but it just covered one product of cherry tomato which is completely symmetrical. They achieved 96% accuracy in all feature mode in their best achievement.

Another interesting research is belonging to Su, Qinghua, et al in 2017 [13]. They worked on potato as the main product. They used depth images to predict potato's features such as length, width, thickness, volume and mass in 3-D model. They used 110 potato samples in different shapes and achieved 93% correct prediction value as their best try.

Gonzalez, Juan Pablo Bonilla et al made an effort to estimate 100 passion fruits' volume and mass. They used just color data and PCA (Principal Component Analysis) [15], LDA (Linear Discriminant Analysis) [15] are used like statistical data analysis and ANN (Artificial Neural Network) [16] as estimation tools and achieved less than 20% error [14].

Wang, Zhenglin et al, used color plus depth images to estimate mango size. They used cascade detection [19] along with Histogram of oriented Gradient (HOG) [17] features to detect the mango and then Otsu's method [19] in CIE color space [7] is used to remove the background, and finally with using ellipse fitting [18] technique just extracted the mango out of the whole image. It is considerable that ellipse fitting removes some parts of mango as mango is not exactly elliptical. They achieved RMSE of 4.9% and 4.3 % for length and width respectively.

Even discriminating a product from others in accumulated situation fits in the depth image capabilities. There is a research which employed Kinect sensor to distinguish specific weed from other products in the field. Andújar, Dionisio, et al used Kinect fusion 3-D reconstruction algorithm to improve final 3-D model of the weeds. Their main goal was to distinguish maize plant from the others. They install their system on an agricultural machine to distinguish, detect and finally analysis plant features. They achieved good correlation of 0.83 with weed biomass [20].

In 2016, Marinello, Francesco, et al attempt to estimate grape product (both black and white) using Kinect sensor in different distances [21]. Also, Wang, Weilin, and Changying Li made a system to measure maximum diameter and volume of sweet onion in 6 different view acquisition system and achieved 96% accuracy [22].

III. Proposed Method

The paper proposes a robust infrared based volume and mass estimation system for fruits and vegetables which fixes some issues in available new and traditional methods. One of the most important part of the project is the preprocessing. There are different types of preprocessing algorithms for color and depth data. For faster process, RGB channels of color image converts to gray level which has two channels. As depth image is two dimensional, this step makes both images in same level as number of dimensions. Some steps of preprocessing on 2-D image are represented in Fig. 4.

System starts with applying median filter and then unsharp mask filter on images. This step applies on both color and depth images which helps for smoothing from inside and sharpening from outside. Preview's step is essential for this step which is canny edge detection filter on color and depth images. After applying edge detection filter, there are two polished edge detected images. Now there are two binary edge detected images which need to be manipulated for filling unnecessary holes using closing morphology operation. After filling the holes, three steps of active contour segmentation, extracting region boundaries and background extraction will be applied [23-25]. Some steps of preprocessing on 3-D image are represented in Fig. 5.

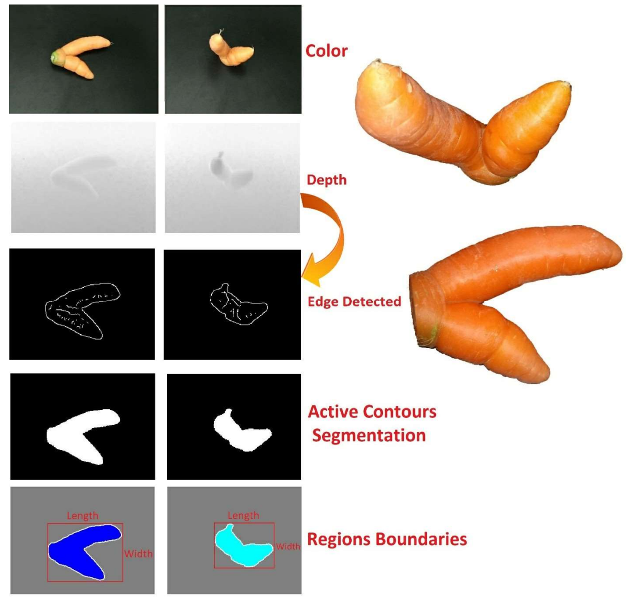

Fig. 4. Some steps of preprocessing on one of the color sample from proposed database (2-D)

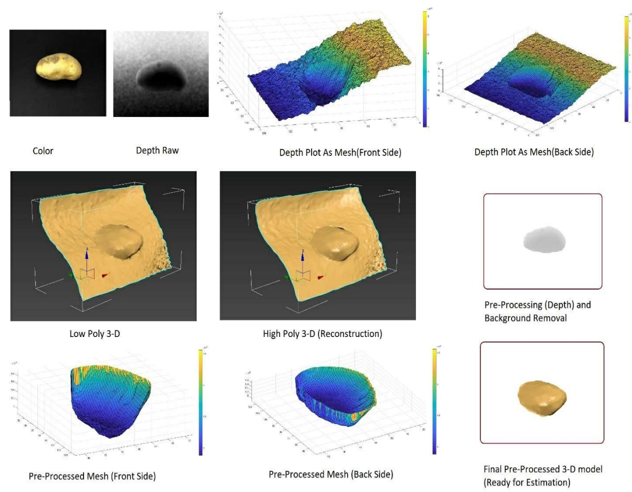

Fig. 5. Some steps of preprocessing on one of the depth sample from proposed database (3-D)

Totally, ten 2-D and 3-D features are extracted from color and depth data. Each feature is described down below in this section. The extracted features from color data are Length, Width, Diameter and Perimeter and extracted features from depth data are Thickness or height, Surface area, Volume, Convex volume, Solidity [26] and Mass. However, just volume and mass are using in comparison purposes, but other features give very essential information for analysis. The final feature vector has size of [1*10], which is used for product classification purpose.

A. *Depth image features*

- 2-D Length, width

To extract 2-D features, color data is used. As, recording range is constant, length and width [34] features are extracted from final background removed image as it is clear in Fig. 6. Length and width features are based on centimeter unit. Length features is calculated from bottom left side of the final cropped version of color data to top or y axis and width feature from same starting position to right or x axis.

- 2-D Diameter

Diameter is twice sized of the radius in circle. But as our experiment fruits are non-symmetrical and carrot is not circular among other circular ones, diameter has different meaning here and it is not diameter exactly. Here diameter means as follow. According to Fig. 6, after background removal and cropping final color image of the fruit, diameter calculations start from first top left pixel in the cropped image which has pixel value more than zero and it end with the same pixel value in bottom right of the image. Finally, a straight line in centimeter determines the diameter value in the proposed method.

- 2-D Perimeter

Perimeter is the distance around the boundary of the region around the 2-D shape. It computes the perimeter by calculating the distance between each adjoining pair of pixels around the border of the region. As, the distance between subject and sensor is constant, it is possible to use pixel number around the 2-D prepressed image.

So, there is final 2-D equation for color image features as Eq. (1):

$$2 - D\ Features\ =\ (L + W + D + P) \quad (1)$$

In which L is Length, W is Width, D is Diameter and P is Perimeter.

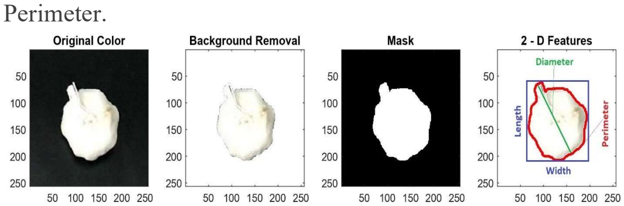

Fig. 6. 2-D Features

- 3-D Thickness or height:

As depth sensor calculates the distance between the sensor and the product, and might some bumps be on the surface of the sample, this may lead the system to a less amount of error which should be considered. Thickness calculates based on highest gray level achieved from the top surface of the sample in depth data. The image stores in a 16-bit matrix of $T\,(x, y)$ in millimeters. As data is recording from two sides and each side gives slightly different value of thickness, so the largest amount of two will be selected.

- 3-D Surface area

Generally, the surface area is the sum of all the areas of all the shapes that cover the surface of the object. As recorded 3-D images have irregular shapes, it is not possible to use common equations to calculate the 3-D surface area value for the object. So, the simplest way to calculate the area of an irregular shape is to subdivide it into familiar shapes, calculate the area of the familiar shapes, then total those area calculations to get the area of the irregular shape they make up. Here, Matlab software is used to calculate all 3-D features in this research.

Used 3-D model is mesh type in the research. So, the model is made of triangular faces, which calculates based on triangle area equation in Eq. (2):

$$Triangle\ Area\ =\ (1/2)\ b * h \quad (2)$$

In which b is the base and h being perpendicular height. For final 3-D surface area equation would be as Eq. (3):

$$3 - D\ Surface\ Area = \sum\nolimits_{Triangle\ Area=}^{n} \text{Triangle Area} = \left(\tfrac{1}{2}\right) b * h \quad (3)$$

- 3-D Volume

All of the 3-D models in the research are based on mesh model, which basically made of triangular shapes. In surface area, it was sum of 2-D tringles area values on the model. But as 2-D shapes have no volume, so triangular prisms make our final 3-D mesh model. So, by calculating sum of the 3-D triangular prisms which makes the final model, 3-D volume of the fruit will be calculated in Eq. (4). The unit of milliliter is used for volume, so the acquired scaler value from Matlab software is normalized to this unit. Fig. 7 shows triangle and triangular prism.

$$3 - D\ Volume = \sum_{Triangular\ Prism\ Volume=1}^{n} Triangular\ Prism\ Volume = \left(\frac{1}{2}\right) b * h * l \quad (4)$$

In which b is the base, h is the height and l are the length.

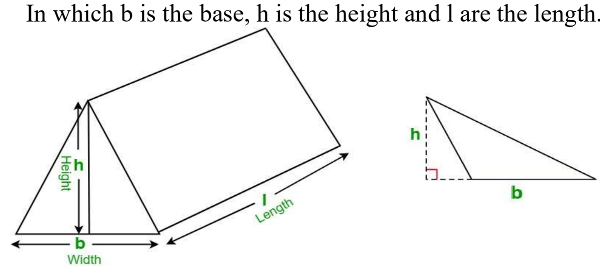

Fig. 7. Triangle and triangular prism

- 3-D Convex volume and Solidity

To understand convex volume better, it is needed to what convex hull is. Given a set of points in the plane, the convex hull of the set is the smallest convex polygon that contains all points of it. Fig. 8 gives a better look to the convex hull. Now, the convex volume is the volume of the convex hull, which its mesh structure is based on triangular calculations. Fig. 9 shows an example of convex volume.

Now a voxel is a raster graphic on a 3-D grid, with the values of length, width and depth. It also contains multiple scalar values such as opacity, color and density. Proportion of the voxels in the convex hull that are also in the region, returned as a scalar which is computed as volume / convex volume is called Solidity [26]. Fig. 10 presents 3-D features for a garlic sample of proposed data.

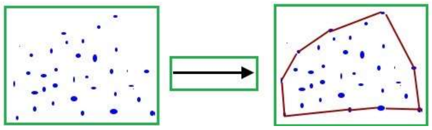

Fig. 8. Convex hull

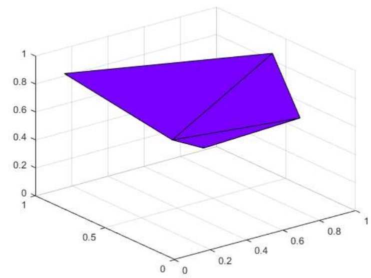

Fig. 9. Convex volume

- 3-D Mass

There is a relation between volume, mass and density [27]. Having two of them, another one is calculable. Each matter has its unique density, which agricultural products are not exception. Garlic has average density of 0.47 g/cm^3, carrot's density is 1.40 g/cm^3, potato's density is 0.63 g/cm^3 and quince's density is 0.91 g/cm$^{3.}$ The gram per cubic centimeter (g/cm^3) [33] is a unit of density in the Centimeter–Gram–Second (CGS) system, commonly used in chemistry, defined as mass in grams divided by volume in cubic centimeters. The relation between density, volume and mass is calculable as Eq. (5):

$$D = \frac{M}{V} \qquad V = \frac{M}{D} \qquad M = D * V \tag{5}$$

In which M is mass, D is Density and V is Volume. Also, for 3-D features there is Eq. (6):

$$3-D\ Features\ = (T + S + V + C + S + M) \tag{6}$$

In which T, S, V, C, S and M are Thickness or height, Surface area, Volume, Convex volume, Solidity and Mass respectively. So, the final feature vector would be as Eq. (7).

$$Final\ Feature\ Vector\ = (L + W + D + P + T + S + V + C + S + M) \tag{7}$$

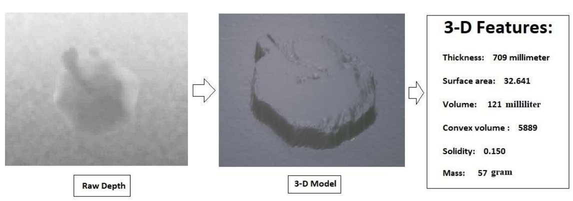

Fig. 10. 3-D features on one of the samples in the experiment

B. Proposed Dataset

Total 60 samples bought from shop in different shapes. These agricultural products are axisymmetric, non-axisymmetric, regular shaped and non-regular shaped. Datasets is consisting of 20 Potatoes, 15 Garlics, 15 Carrots and 10 Quinces in different shapes and sizes.

Three Every Day Carry (EDC) LED Bulb 9 w power with 6000k temperature lights are used as main source of light. Background is black and Kinect sensor is placed in 0.8-meter distance from subject (this distance could be modified due to distance detection capability of depth sensor).

Windows 10 64-bit operating system along with MATLAB R 2019 b software are used for recording the dataset and getting the final evaluations results. Also, the hardware setup for processing is as follow: Intel Core I-7 4790-K CPU 4.00 GHz, 32 GB of RAM, NVIDIA GeForce GTX 1050 2GB.

Fig. 11 represents the recoding environment setup. Also, Fig. 12 presents one of the Quince samples in color mode and Fig. 13 shows some of the recorded samples in color and depth mode along with their identifier number in the dataset.

Fig. 11. Recording setup environment

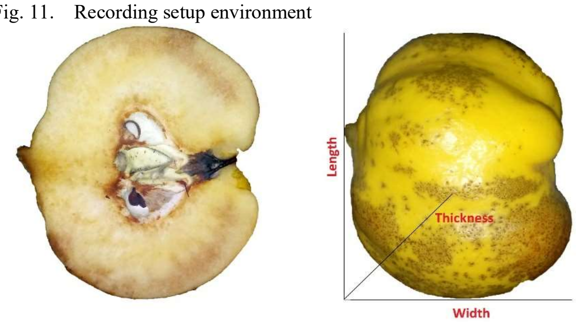

Fig. 12. One of the Quince sample in color mode

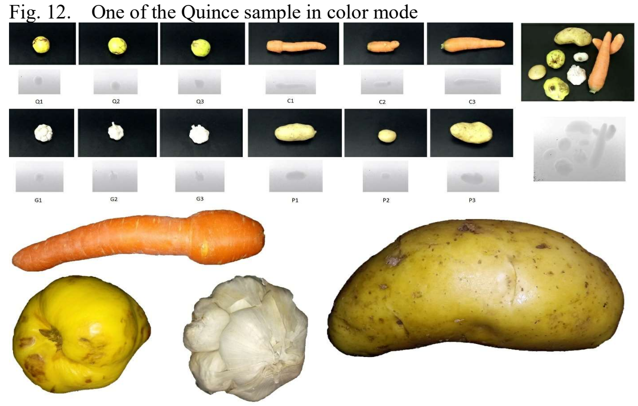

Fig. 13. Some samples from proposed dataset

IV. Validation and Results

Validation consists of comparison between proposed method and original and traditional volume and mass estimation methods of WD and DB along with the most related researches of [10], [2] and [11]. Validation error metrics or tools are Mean absolute error (MAE) [28] and Mean Absolute Percentage Error (MAPE) [29]. As it mentioned earlier, all acquired results for volume are in milliliter and mass in gram.

In order to increase the readability of the paper, an abbreviation table is added along with necessary comments which is Table I. Table II, III, IV and V present the comparison between acquired volume and mass results for potato, garlic, carrot and quince agricultural products using proposed method and other similar and original WD and DB methods along with proposed method's runtime speed in second.

TABLE I. PAPER ABBREVIATIONS TABLE

Definition	Abbreviation	Description
Water Displacement method (WD)	WD	Traditional volume calculation system
Digital Balance	DB	Traditional mass calculation system
RGB-D (Red Green Blue – Depth)	RGB-D	Kinect data type
Time of Flight	TOF	Kinect V.2 technology
Root Mean Square Error	RMSE	
MAE	Mean Absolute Error	
MAPE	Mean Absolute Percentage Error	
Every Day Carry	EDC	A type of light
Centimeter–Gram–Second system	CGS	A centimeter-based metric system
3-Dimentional	3-D	
2.5-Dimentional	2.5-D	Raw depth image dimensions
2-Dimentional	2-D	
D	Density	
V	Volume	
M	Mass	
Gram per cubic centimeter	g/cm	Unit of density
Milliliter	ml	Unit of volume
Gram	g-gm	Unit of mass
Second	sec	Unit of time

- Mean Absolute Error:

The Mean Absolute Error (MAE) [28] measures the average magnitude of the errors in a set of predictions, without considering their direction. It's the average over the test sample of the absolute differences between prediction and actual observation where all individual differences have equal weight. MAE formula is shown in Eq. (8).

$$MAE: \frac{1}{n}\sum_{j=1}^{n} |y_j - \hat{y_j}| \quad (8)$$

In which n is total number of samples, y_j is actual output value and $\hat{y_j}$ is predicated output value.

- Mean Absolute Percentage Error:

The Mean Absolute Percentage Error (MAPE) [29] is a statistical measure of how accurate a predict system is. It measures this accuracy as a percentage, and can be calculated as the average absolute percent error for each time period minus actual values divided by actual values. MAPE equation is as Eq. (9).

$$MAPE: \frac{1}{n}\sum_{j=1}^{n} |\frac{y_j - x_j}{y_j}| \quad (9)$$

Where y_j actual output value and x_j is predicated output value.

Fig. 14 shows the differences between proposed volume estimation results versus original WD for all garlic samples. Also, Fig. 15 plots proposed mass estimation results versus original DB method for all carrot samples. Table VI contains the MAE and MAPE values for volume and mass factors which are calculated for all other [10], [2], [11] and proposed methods with original WD and DB methods for all sample of four selected agricultural products. Fig. 16 presents the acquired results of Table VI, in graphical form.

Linear regression attempts to model the relationship between two variables by fitting a linear equation to observed data. One variable is considered to be an explanatory variable, and the other is considered to be a dependent variable. Fig. 17 shows linear regression [30] results for potato samples. In Fig. 17 and from left to right, there are volume result for proposed method and WD method, mass result for proposed method and DB method and finally, proposed volume and proposed mass estimation results.

A box plot [31] is a type of chart often used in explanatory data analysis to visually show the distribution of numerical data and skewness through displaying the data quartiles and averages. The acquired results in Tables II, III, IV and V are box plotted in Fig. 18 for better readability.

As it mentioned earlier, the system extracts 10 2-D and 3-D features out of color and depth data, and these features are saved as feature vectors for all four classes. These feature vectors could be used in agricultural products detection system. But as a small research, it is found that system could detect employed samples out of any other agricultural products and this system can use just depth images for detection with high accuracy. As it is clear in Fig. 19, the average detection accuracy of the system is 99 % using common Support Vector Machine SVM [32] classifier. It was a small part of the experiment, so it is decided to mention it.

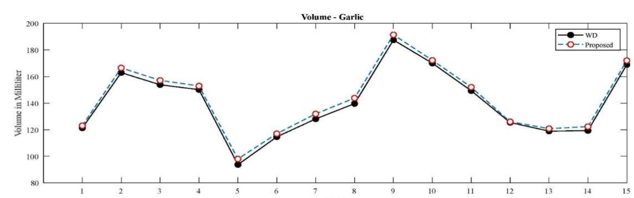

Fig. 14. Comparison results for proposed volume estimation method versus WD method for garlic samples in milliliter

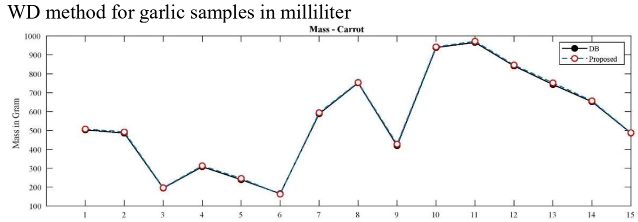

Fig. 15. Comparison results for proposed mass estimation method versus DB method for carrot samples in gram

TABLE II. COMPARISON RESULTS FOR POTATO SAMPLES

Sample	Volume (ml) – (D = 0.63 g/cm^3)					Mass (gm)					Run time (sec)
Potato	**WD**	**[10]**	**[2]**	**[11]**	**Proposed**	**DB**	**[10]**	**[2]**	**[11]**	**Proposed**	**Proposed**
P01	462.0	453.6	447.0	474.8	466.1	291.06	285.76	281.61	299.12	293.64	0.61
P02	317.1	308.7	302.1	329.9	318.3	199.77	194.48	190.32	207.83	200.52	0.69
P03	252.0	243.6	237.0	264.8	256.3	158.76	153.46	149.31	166.82	161.46	0.65
P04	342.3	333.9	327.3	355.1	347.9	215.64	210.35	206.19	223.71	219.17	0.51
P05	333.9	325.5	318.9	346.7	340.6	210.35	205.06	200.90	218.42	214.57	0.58
P06	212.1	203.7	197.1	224.9	218.7	133.62	128.33	124.17	141.68	137.78	0.61
P07	602.7	594.3	587.7	615.5	608.8	379.70	374.40	370.25	387.76	383.54	0.59
P08	632.1	623.7	617.1	644.9	635.6	398.22	392.93	388.77	406.28	400.42	0.49
P09	651.0	642.6	636.0	663.8	653.3	410.13	404.83	400.68	418.19	411.57	0.56
P10	854.7	846.3	839.7	867.2	856.3	538.46	533.16	529.01	546.33	539.46	0.71
P11	235.2	226.8	220.2	248.2	236.4	148.17	142.88	138.72	156.36	148.93	0.77
P12	300.3	291.9	285.3	313.1	302.8	189.18	183.89	179.73	197.25	190.76	0.69
P13	317.1	308.7	302.1	329.9	323.1	199.77	194.48	190.32	207.83	203.55	0.57
P14	585.9	577.5	570.9	598.7	592.2	369.11	363.82	359.66	377.18	373.08	0.58
P15	537.6	529.2	522.6	550.4	539.7	338.68	333.39	329.23	346.75	340.01	0.62
P16	392.7	384.3	377.7	405.5	400.8	247.40	242.10	237.95	255.45	252.50	0.68
P17	342.3	333.9	327.3	355.1	347.3	215.64	210.35	206.19	223.71	218.79	0.59
P18	535.5	527.1	520.5	548.3	538.4	337.36	332.07	327.91	345.42	339.19	0.78
P19	363.3	354.9	348.3	376.1	366.9	228.87	223.58	219.42	236.94	231.14	0.81
P20	758.1	749.7	743.1	770.9	759.7	477.60	472.31	468.15	485.66	478.61	0.56

TABLE III. COMPARISON RESULTS FOR GARLIC SAMPLES

Sample	Volume (ml) – (D = 0.47 g/cm^3)					Mass (gm)					Run time (sec)
Garlic	**WD**	**[10]**	**[2]**	**[11]**	**Proposed**	**DB**	**[10]**	**[2]**	**[11]**	**Proposed**	**Proposed**
G 01	121.3	113.6	112.1	127.1	123.0	57.01	53.39	52.69	59.74	57.81	0.51
G 02	162.9	155.2	153.7	168.7	166.5	76.56	72.94	72.24	79.29	78.26	0.69
G 03	153.8	146.1	144.6	159.6	157.1	72.29	68.67	67.96	75.01	73.84	0.48
G 04	150.1	142.4	140.9	155.9	152.9	70.55	66.93	66.22	73.27	71.86	0.53
G 05	93.7	86.0	84.50	99.50	98.0	44.04	40.42	39.71	46.77	46.06	0.52
G 06	114.6	106.9	105.4	120.4	117.0	53.86	50.24	49.54	56.59	54.99	0.56
G 07	128.1	120.4	118.9	133.9	131.9	60.21	56.59	55.88	62.93	61.99	0.57
G 08	139.6	131.9	130.4	145.4	143.8	65.61	61.99	61.29	68.34	67.59	0.41
G 09	187.5	179.8	178.3	193.3	191.4	88.13	84.51	83.80	90.85	89.96	0.69
G 10	170.0	162.3	160.8	175.8	172.2	79.90	76.28	75.58	82.63	80.93	0.71
G 11	149.3	141.6	140.1	155.1	152.0	70.17	66.55	65.85	72.90	71.44	0.69
G 12	125.4	117.7	116.2	131.2	126.0	58.94	55.32	54.61	61.66	59.22	0.62
G 13	118.9	111.2	109.7	124.7	120.8	55.88	52.26	51.56	58.61	56.78	0.61
G 14	119.3	111.6	110.1	125.1	122.3	56.07	52.45	51.75	58.80	57.48	0.58
G 15	168.9	161.2	159.7	174.7	172.0	79.38	75.76	75.06	82.11	80.84	0.59

TABLE IV. COMPARISON RESULTS FOR CARROT SAMPLES

Sample	Volume (ml) – (D = 1.4 g/cm^3)					Mass (gm)					Run time (sec)
Carrot	**WD**	**[10]**	**[2]**	**[11]**	**Proposed**	**DB**	**[10]**	**[2]**	**[11]**	**Proposed**	**Proposed**
C 01	359.3	348.7	350.6	368.8	362.4	503.02	488.18	490.84	516.32	507.36	0.71
C 02	346.8	336.2	338.1	356.3	351.8	485.52	470.68	473.34	498.82	492.52	0.72
C 03	139.2	128.6	130.5	148.7	140.5	194.88	180.04	182.70	208.18	196.70	0.89
C 04	220.0	209.4	211.3	229.5	223.6	308.00	293.16	295.82	321.30	313.04	0.59
C 05	170.8	160.2	162.1	180.3	175.8	239.12	224.28	226.94	252.42	246.12	0.63
C 06	117.6	119.0	120.9	139.1	116.7	165.44	166.60	169.26	194.74	162.78	0.69
C 07	419.9	409.3	411.2	429.4	424.2	587.86	573.02	575.68	601.16	593.88	0.57
C 08	536.9	526.3	528.2	546.4	538.5	751.66	736.82	739.48	764.96	753.90	0.52
C 09	299.6	289.0	290.9	309.1	305.3	419.44	404.60	407.26	432.74	427.42	0.67
C 10	670.2	659.6	661.5	679.7	673.2	938.28	923.44	926.10	951.58	942.48	0.72
C 11	689.8	679.2	681.1	699.3	694.3	965.72	950.88	953.54	979.02	972.02	0.63
C 12	601.0	590.4	592.3	610.5	604.7	841.40	826.56	829.22	854.70	846.58	0.64
C 13	530.6	520.0	521.9	540.1	537.0	742.84	728.00	730.66	756.14	751.80	0.58
C 14	465.6	455.0	456.9	475.1	469.1	651.84	637.00	639.66	665.14	656.74	0.78
C 15	347.4	336.8	338.7	356.9	348.3	486.36	471.52	474.18	499.66	487.62	0.70

TABLE V. COMPARISON RESULTS FOR QUINCE SAMPLES

Sample	Volume (ml) – (D = 0.91 g/cm^3)					Mass (gm)					Run time (sec)
Quince	**WD**	**[10]**	**[2]**	**[11]**	**Proposed**	**DB**	**[10]**	**[2]**	**[11]**	**Proposed**	**Proposed**
Q 01	329.5	322.3	320.9	337.4	331.5	299.85	293.29	292.02	307.03	301.67	0.64
Q 02	313.3	306.1	304.7	321.2	316.9	285.10	278.55	277.28	292.29	288.38	0.59
Q 03	269.9	262.7	261.3	277.8	271.6	245.61	239.06	237.78	252.80	247.16	0.53
Q 04	197.0	189.8	188.4	204.9	199.0	179.27	172.72	171.44	186.46	181.09	0.50
Q 05	286.3	279.1	277.7	294.2	288.2	260.53	253.98	252.71	267.72	262.26	0.56
Q 06	225.6	218.4	217.0	233.5	229.3	205.30	198.74	197.47	212.49	208.66	0.63
Q 07	203.9	196.7	195.3	211.8	206.2	185.55	179.00	177.72	192.74	187.64	0.76
Q 08	412.6	405.4	404.0	420.5	415.3	375.47	368.91	367.64	382.66	377.92	0.70
Q 09	568.9	561.7	560.3	576.8	571.7	517.70	511.15	509.87	524.89	520.25	0.68
Q 10	398.2	391.0	389.6	406.1	401.5	362.36	355.81	354.54	369.55	365.37	0.62

TABLE VI. ERROR RESULTS FOR ALL METHODS AND ALL SAMPLES (VOLUME AND MASS)

	Volume		Mass	
	MAE	**MAPE**	**MAE**	**MAPE**
Potato	[10] = 8.40 [2] = 15.00 [11] = 12.79 Proposed = 4.06	[10] = 2.16 [2] = 3.86 [11] = 3.30 Proposed = 1.09	[10] = 5.29 [2] = 9.45 [11] = 8.06 Proposed = 2.56	[10] = 2.12 [2] = 3.88 [11] = 3.32 Proposed = 1.08
Garlic	[10] = 7.70 [2] = 9.20 [11] = 5.80 Proposed = 2.90	[10] = 5.67 [2] = 6.77 [11] = 4.27 Proposed = 2.12	[10] = 3.62 [2] = 4.32 [11] = 2.72 Proposed = 1.36	[10] = 5.61 [2] = 6.75 [11] = 4.22 Proposed = 2.10
Carrot	[10] = 9.98 [2] = 8.34 [11] = 10.30 Proposed = 3.50	[10] = 3.07 [2] = 2.64 [11] = 3.90 Proposed = 1.04	[10] = 13.92 [2] = 11.62 [11] = 14.36 Proposed = 4.99	[10] = 3.03 [2] = 2.61 [11] = 3.86 Proposed = 1.10
Quince	[10] = 7.20 [2] = 8.60 [11] = 7.90 Proposed = 2.60	[10] = 2.48 [2] = 2.96 [11] = 2.72 Proposed = 0.88	[10] = 6.55 [2] = 7.82 [11] = 7.18 Proposed = 2.36	[10] = 2.48 [2] = 2.97 [11] = 2.72 Proposed = 0.89

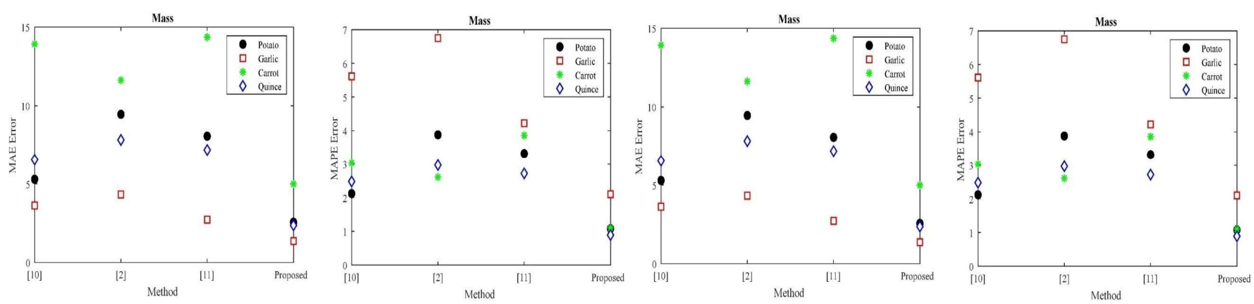

Fig. 16. Graphical plot of acquired error results in Table 6

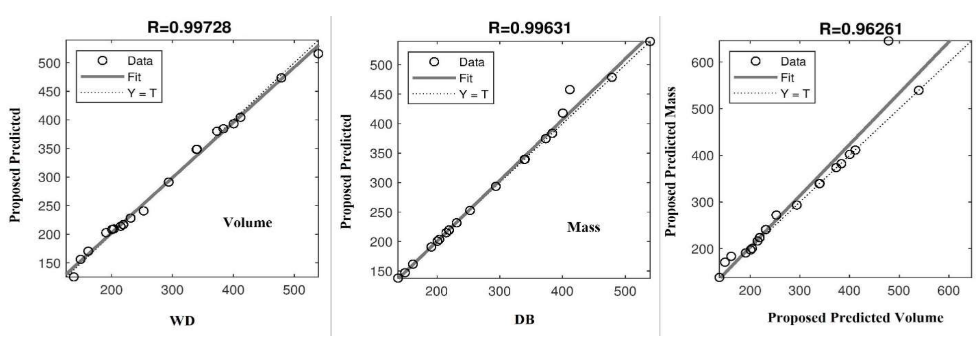

Fig. 17. Linear regression for potato samples (Proposed vs WD (volume)- Proposed vs DB (mass)- Proposed vs Proposed (volume and mass))

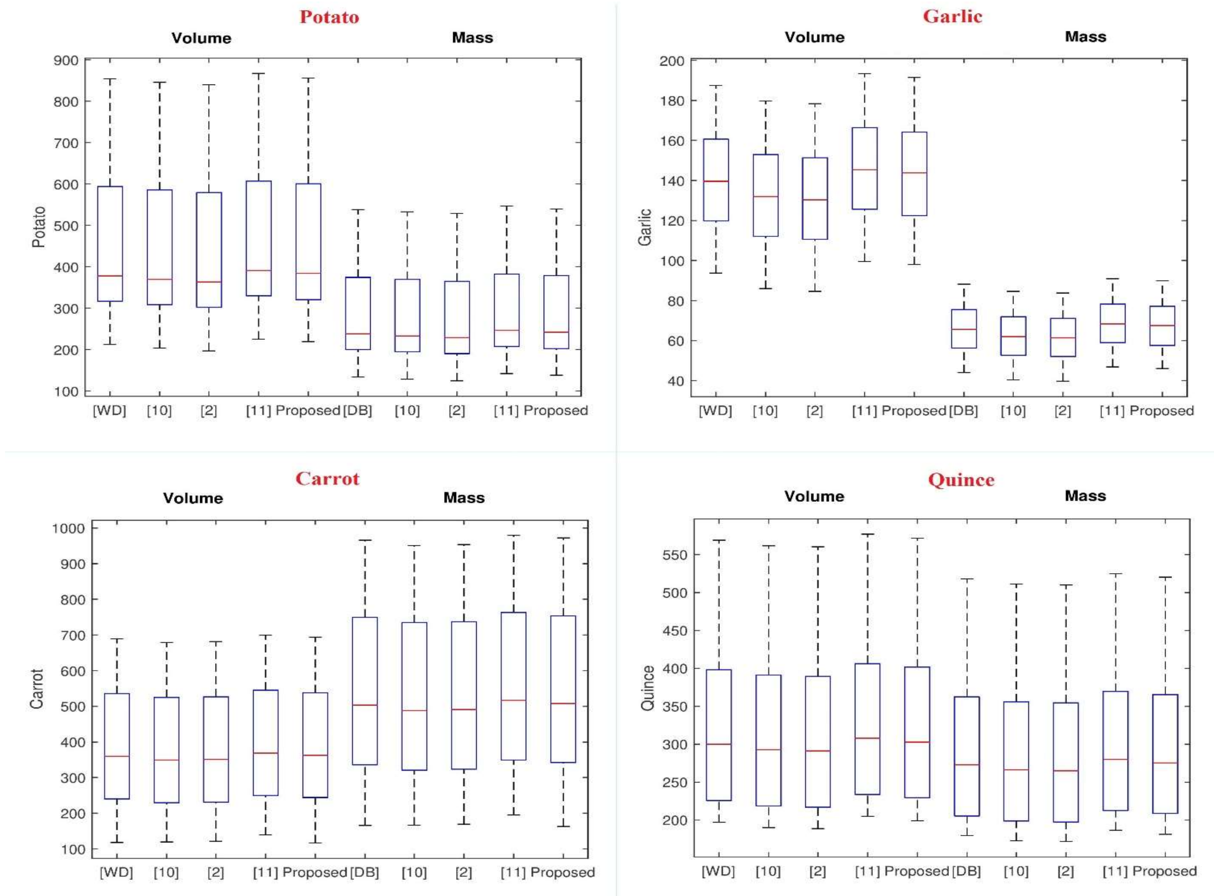

Fig. 18. Box plot for all samples and all methods (volume and mass)

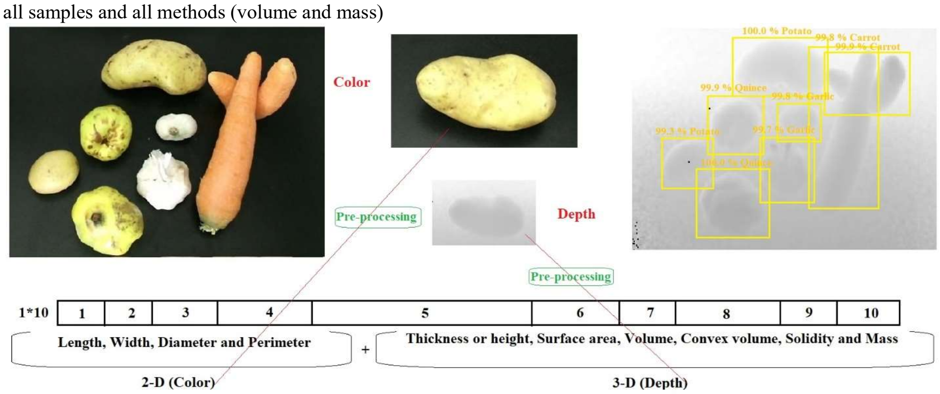

Fig. 19. Using extracted features on a depth image sample

As it is clear in Tables II, III, IV and V, methods [2] and [10] provided less values than original WD and DB methods values in all experiments for volume and mass estimations and method [11] always provides more values than original methods values. Proposed method has closer values to original methods values and in average is more promising than other three similar methods, as the error values in Table VI indicates this matter.

V. CONCLUSION, DISCUSSION AND SUGGESTIONS FOR FUTURE WORKS

Adding depth data to color data, increases the final detection and recognition accuracy in agricultural grading automatic systems. Here Microsoft Kinect sensor is employed to perform the task for volume and mass estimation of irregular and non-symmetrical agricultural products. As system uses inferred spectrum for depth data, it could be used in pure darkness condition. To have more accurate results, 3-D extracted features are added to 2-D extracted features which fixes traditional and color-based methods weaknesses. As the system is single image based and non-learning based, so the runtime speed is less than similar methods which is an advantage. Also, due to cheap price of the proposed system, it is rational to replace this digital system with traditional heavy machinery which always damages the agricultural products and contains huge amount of final error in mass and volume estimation in high number of products. It is suggested to use more fruits or vegetables in the system. Also, it is suggested to use more than two angles for agricultural products or using more sensors for simultaneous recording. As other similar methods just predict volume and mass, two out of 10 extracted features are use in the comparison part, and other eight extracted features could be used in agricultural product quality analysis and classification systems, which is of future works.

- Conflict of interest

The authors also declare that there is no conflict of interest.

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