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Determination of Tangerine Volume Using Image Processing

Mostafa KHOJASTEHNAZHAND, Mahmoud OMID, Ahmad TABATABAEEFAR
Dept. of Agricultural Machinery Engineering, Faculty of Biosystems Engineering, University of Tehran, Karaj, Iran.
omid@ut.ac.ir

ABSTRACT: Fruit size, dimensions and its geometrical attributes are important physical properties of agricultural produce. More specifically, the estimation of mean fruit size is needed in meeting quality standards, increasing market value, monitoring fruit growth, predicting yields and assessing optimal levels of fertilization and irrigation, as well as the design and development of sizing mechanisms. In this study, tangerine volume was measured using image processing technique. The actual volume of tangerine was obtained by water displacement method. In image processing method, we used two CCD cameras that were situated at right angle to each other in order to give us two perpendicular images of tangerines. By removing the background and dividing the image into a number of distinct sectors, we were able to calculate the surface area and volume of each sector. The volume of fruit was then obtained by adding up the volume of all sectors. Fifty tangerines in three replications were examined to determine the accuracy of the algorithm. The volume obtained from image processing was compared to the actual volume determined by the water displacement method using the *t-test*. The obtained result was not significantly different from the actual volume ($P > 0.05$). In conclusion, image processing technique provides a simple and efficient methodology for estimating tangerine volume.

Key words: Tangerine; Volume; Image Processing; Sorting; Sizing Mechanisms

INTROUDUCTION

Fruit size, dimensions and its geometrical attributes are important physical properties of agricultural produce. More specifically, the estimation of mean fruit size is needed in meeting quality standards, increasing market value(Wilhelm et al., 2005), monitoring fruit growth, predicting yields and assessing optimal levels of fertilization and irrigation, as well as the design and development of sizing mechanisms. Fruit size estimation is also helpful in planning packaging, transportation and marketing operations. Among the physical attributes of agricultural materials, volume, mass and projected areas are the most important ones in sizing systems (Tabatabaeefar and Rajabipour, 2005; Wright et al., 1986; Safwat and Moustafa, 1971). There are some situations in which it is desirable to determine relationships among physical characteristics; for example, fruits are often graded by size, but it may be more economical to develop a machine vision system which grades by weight or volume. The size of an agricultural produce is frequently represented by its weight because it is relatively simple to measure. However, volume-based sorting and growth monitoring may provide a more efficient method than weight sorting. In addition, the weight of agricultural produce can be estimated from volume if the density of the produce is known. Ngouajio et al. (2003) and Hall et al. (1996) developed simple model equations to estimate the volume of bell pepper and kiwifruit from each object's dimensions. However, measuring dimensions using a digital caliper, subject to human error, may not be an efficient and practical approach to estimate volume, particularly in sorting large quantities of agricultural produce indoors or in monitoring yield during harvesting.

In recent years, machine vision and image processing techniques have been found increasingly useful in the fruit industry, especially for applications in quality inspection and shape sorting. Researches in this area indicate the feasibility of using machine vision systems to improve product quality while freeing people from the traditional hand sorting of agricultural materials. Currently, machine vision is the most effective tool for external feature measurements such as color intensity, color homogeneity, bruises, size, shape and stem identification (Lee et al., 1999; Majumdar and Jayas, 2000; Shahin and Symons, 2001; Paliwal et al., 2003; Shigeta et al., 2004; Shahin et al., 2004; Abbasgholipour et al., 2006; Jafari, et al., 2006). The use of machine vision is gaining interest for the volume determination of fruit and irregular-shaped objects, because it is a nondestructive method requiring image analyses and image processing operations. A machine vision algorithm using neural networks was developed by Forbes and Tattersfield (1999) for the estimation of pear fruit volume from two-dimensional digital images. The RMS percentage error using a single digital image was 3.0%. This percentage was reduced to 1.9% when the volume was estimated from sets of four images. Lorestani et al. (2006) developed a fuzzy logic based algorithm for sorting of Golden Delicious apples. Features such as color and size are measured through a data acquisition system consisted of apple's sorter, illumination chamber, webcam and a PC. Grading results obtained from the developed machine vision system showed 91.2% and 95.2% agreement for off-line and online methods, respectively, with the results from the human expert. Hahn and Sanchez (2000) developed an imaging algorithm to measure the volume of non-circular shaped agricultural produce, such as carrots. Sabliov et al. (2002) used an image-processing algorithm to determine the surface area and volume of axi-symmetric agricultural products. Wang and Nguang (2007) designed a low-cost sensor using the methodology developed by Sabliov et al. (2002) to measure the volume and surface area of agricultural products. They created a representation of the produce with a set of elementary cylindrical objects of unit pixel height and estimated the volume by summing the elementary volumes of individual cylinders. Bailey et al. (2004) demonstrated an image processing approach which estimated the weight of agricultural products rapidly and accurately. Bulent-Koc (2007) determined the watermelon volume using ellipsoid approximation and image processing and compared them with water displacement method to determine system accuracy.

The objective of this paper is to develop an efficient algorithm for volume determination of tangerines based on machine vision. The estimation of tangerine volume is important for size sorting, monitoring growth development under various management practices or developing a yield-monitoring sensor. The proposed image processing technique is very general and can provide an alternative method to estimate the volume of axi-symmetric agricultural products such as tangerine, onion, melon, kiwifruit, pomegranate and pear.

MATERIALS and METHODS

Fifty randomly tangerines of various sizes were selected and purchased from a local market. The weight of each tangerine was measured on a digital balance with an accuracy of ± 0.01 gr. The minimum and maximum weights were 59.8 and 99.4 gr, respectively. The actual volume of tangerines were measured by the displacement water method (Akar and Aydin, 2005; Aydin and Musa Ozcan, 2007). For this purpose, a tangerine was submerged into the known water and the volume of water displaced was measured. Water temperature was kept at 25°C. Specific gravity of each tangerine was calculated by the mass of tangerines in air divided by the mass of displaced water.

In order to determine the dimensions and volume of tangerines a machine vision system designed, developed and tested. The proposed machine vision system consists of two CCD cameras, two capture cards, an appropriate lighting system, a personal computer (Fig. 1).

A white cardboard was placed on a table to provide a white background. The cameras were placed at right angle to each other in order to capture two perpendicular images of each tangerine. The light source and cameras mounted on a frame was attached to the measurement table. Algorithms were implemented using Visual Basic 6.0 programming language. The program was developed to capture and record the surface images of the tangerine. Each tangerine was placed at the center of the cameras' field of view and two RGB color images were captured. To extract the fruit image, the acquired image was subtracted from background image by calculating RGB of any pixel of fruit image. Obtained RGB compared with background RGB. If the difference between the obtained RGB values and the background RGB was less than 5, this pixel would be background else it is fruit. To calibrate the system, an object with distinctive dimension similar to tangerine was selected. The acquired dimension data by system compared with actual dimension of object then the system were calibrated.

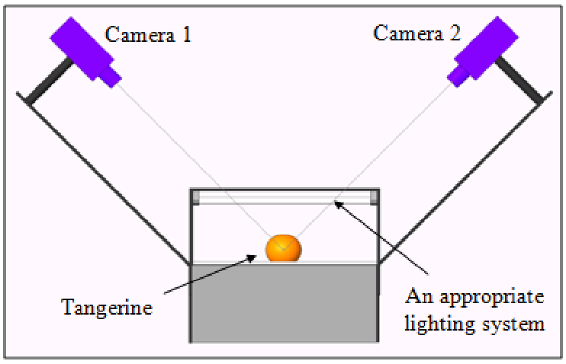


Fig. 1. Schematic of developed machine vision system.

To determine the volume of tangerine, images of fruit captured and subtracted the background from images. Calculating errors of volume decreased by removing the background and dividing the image into a number of distinct sectors, (Fig. 2a and 2b). Surface area of each sector can be calculated using two perpendicular diameters from two perpendicular images of tangerine, (Fig. 2c). The surface area of each sector, $(A_i, \quad i = 1,2,\cdots,n)$, is given by:

$$A_i = \pi \times \frac{d_{i_1}}{2} \times \frac{d_{i_2}}{2} \qquad (1)$$

where d_{i_1} and d_{i_2} are the two perpendicular diameters of surface.

Volume of each sector $(V_i, \quad i = 1,2,\cdots,n)$ is calculated by (Fig. 4d):

$$V_i = \frac{A_i + A_{i+1}}{2} \times \delta \qquad (2)$$

where A_i and A_{i+1} are surface areas in i and $i+1$ segments, respectively, and δ is thickness of segment, assuming all segments are of equal thicknesses. The accuracy of estimated surface area depends on the position of minimum and maximum diameters of the tangerine's surface.

Once the volume of all sectors is obtained, the volume of tangerine (V_t) can be readily calculated by adding them up:

$$V_t = \sum_{i=1}^{n} V_i \qquad (3)$$

where n is the number of sectors.

A paired *t*-test and the mean difference confidence interval approach were used to compare the volume determined from segmentation techniques with that of water displacement method. The paired *t*-test is used here for testing whether the difference between two measurements is significantly different. The important feature of this test is that it compares the measurements within each subject. The Bland and Altman (1999) approach was also used to plot the agreement between tangerine volume measured by water displacement (actual) with the ellipsoid segmentation method (calculated). The statistical analyses were performed with Analysis-it, an Excel add-in program.

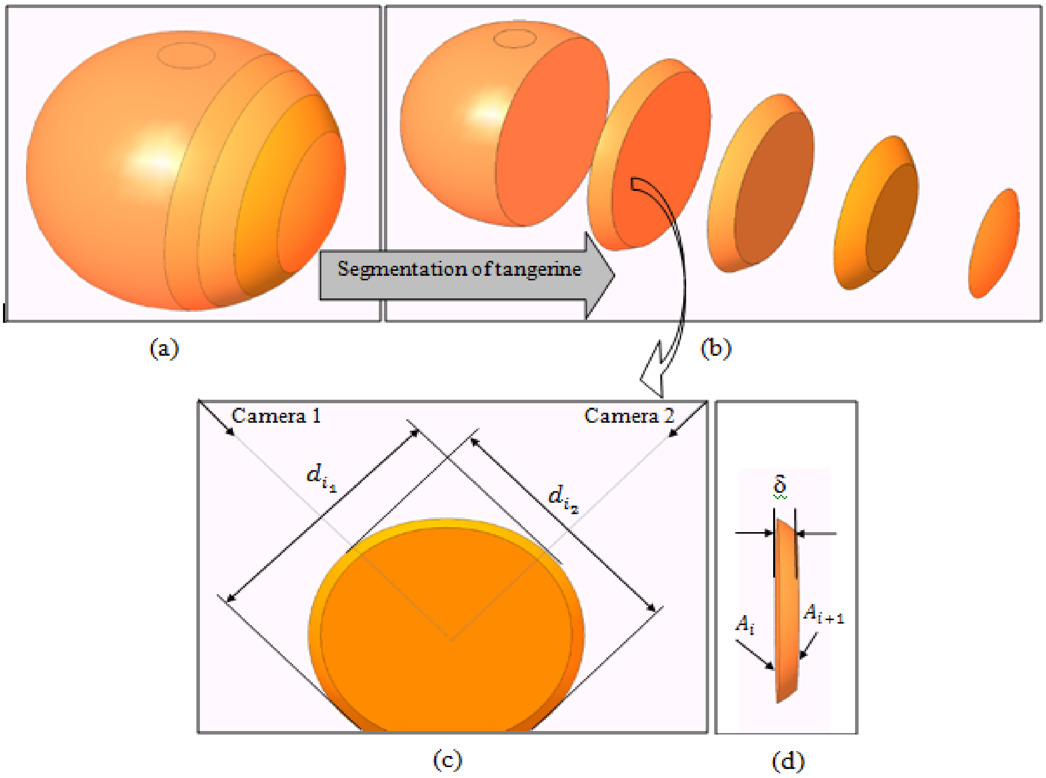
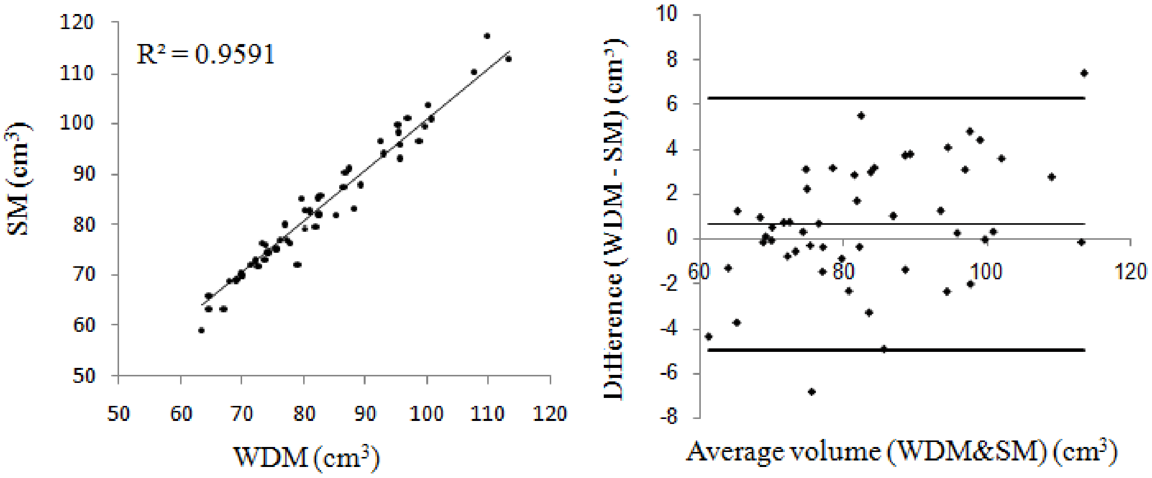


Fig. 2. (a) Tangerine fruit; (b) Segmentation of tangerine; (c) Extraction of two diameters of one surface of one sector; (d) Thickness of sector and its surface areas

RESEARCH RESULTS

The volume determined by *segmentation* method was compared with the mean volume measured by water displacement method. A plot of the volumes measured by segmentation method and water displacement is shown in Fig. 3a. The mean volume difference between the two methods was d_2 = 0.66 cm^3 (95% confidence interval: -0.14 and 1.45 cm^3). The standard deviation of the volume difference was sd_2 = 2.8 cm^3. The paired *t-test* results showed that the volume measured with segmentation method was not significantly different than the volume measured with water displacement (P = 0.1032). The volume differences between segmentation method and water displacement were also normally distributed and the 95% limits of agreement in comparing these two methods were calculated to be -4.83 and 6.14 cm^3 (Fig. 3b).

Fig. 3b shows that tangerine's size has not effect on estimation of volume. In spite of Bulent Koc (2007) reported that as the size of the watermelon increased, the image processing method overestimated the volume. This can be attributed to the more sophisticated image processing method used here. The method used here is rotationally invariant and does not require fruit alignment on the conveyor. The average percentage difference for volume estimation with segmentation method was 2.6%.



(a) (b)

Fig. 3. (a) Tangerine volume measured using water displacement method (WDM) and segmentation method (SM) with the line of equality; (b) Bland–Altman plot for the comparison of tangerine volumes measured with water displacement and segmentation methods; outer lines indicate the 95% limits of agreement (-4.83 ; 6.14 cm^3) and center line shows the average difference (0.66 cm^3)

DISCUSSION AND CONCLUSION

A novel approach for the estimation of tangerine's volume, based on machine vision system, was presented. The methodology is quite general and can be to other axi-symmetric agricultural products including onion, melon, kiwifruit and pear.

The estimated volume by the segmentation method was compared to the volume measured with the water displacement method. The difference between the two methods was not statistically significant (*P* > 0.05). The Bland–Altman approach showed that tangerine's size has no effect on the estimation of volume.

In conclusion, image processing with segmentation method provides a simple, rapid and non-invasive method to estimate tangerine volume and can be easily implemented in monitoring the growth rate of tangerines in the field, monitoring yield during mechanical harvesting, estimating the weight of individual tangerines and sorting of tangerines indoors during postharvest processing in a fully automated sorting machine.

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