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Estimating volume and mass of citrus fruits by image processing technique

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ABSTRACT

An image processing based technique was developed to measure volume and mass of citrus fruits such as lemons, limes, oranges, and tangerines. The technique uses two cameras to give perpendicular views of the fruit. An efficient algorithm was designed and implemented in Visual Basic (VB) language. The product volume was calculated by dividing the fruit image into a number of elementary elliptical frustums. The volume is calculated as the sum of the volumes of individual frustums using VB. The volumes computed showed good agreement with the actual volumes determined by water displacement method. The coefficient of determination (R^2) for lemon, lime, orange, and tangerine were 0.962, 0.970, 0.985, and 0.959, respectively. The Bland–Altman 95% limits of agreement for comparison of volumes with the two methods were (−1.62; 1.74), (−7.20; 7.57), (−6.54; 6.84), and (−4.83; 6.15), respectively. The results indicated citrus fruit's size has no effect on the accuracy of computed volume. The characterization results for various citrus fruits showed that the volume and mass are highly correlated. Hence, a simple procedure based on computed volume of assumed ellipsoidal shape was also proposed for estimating mass of citrus fruits. This information can be used to design and develop sizing systems.

1. Introduction

Annual citrus production in Iran is 3.5 million tonnes, which is ranked as sixth in the world. Before being exported, all citrus fruits are subjected to inspection for quality control purpose and are graded according to their size, maturity, and presence of defect. The size of a citrus fruit is often represented by its mass because it is relatively simple to measure. Currently, the measurement is done manually by weighing individual citrus fruits to get a uniform size prior to packaging. However, this manual weighing procedure is time consuming, inefficient, and labor-intensive.

Physical characteristics of agricultural products are the most important parameters in determining the proper standards of design of grading, conveying, processing, and packaging systems. The major physical properties of citrus fruits are shape, size, density, porosity, volume, and mass of fruits and friction against various surfaces (Akar and Aydin, 2005). These properties have been studied for various agricultural products such as breadfruit, terebinth fruits, onion, almond, caper, myrtle, and pomegranate (Omobuwajo et al., 1999; Aydin and Ozcan, 2002; Abhayawick et al., 2002; Aydin, 2003; Sessiz et al., 2007; Aydine and Ozcan, 2007; Khoshnam et al., 2007). There are some situations in which it is desirable to determine relationships among geometric dimensions. 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. Simple model equations to estimate the mass of various agricultural products such as apple, pomegranate, and apricot are available (Tabatabaeefar and Rajabipour, 2005; Khoshnam et al., 2007; Naderi-Boldajia et al., 2008). However, measuring dimensions using a digital caliper is subject to human error and may not be an efficient and practical approach to estimate volume, particularly in sorting large quantities of agricultural products indoors or in monitoring yield during harvesting.

In fruits and vegetables size, mass, volume, and density attributes are somewhat correlated. Volume and mass together, determine fruit density related to produce consistency and flavor. Volume can also be used for harvest time prediction (Hahn and Sanchez, 2000). For instance, volume used as a fruit and vegetable sorting feature shows a 0.91 correlation coefficient with length on jalapeno chilli grading (Hahn et al., 1997). Differences in density have also been utilized for quality inspection such as seed viability test and citrus granulation test. Different mathematical models and numerical analysis methods have been applied to extract a representation of volume. Some commonly used methods to determine volume include geometric mean diameter, water displacement method, and gas displacement method.

In recent years, machine vision has been found increasingly useful in agricultural and food industry, especially for applications in quality inspection, meeting quality standards, and increasing market value. In fact, machine vision is the most effective tool

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for measuring external features such as color intensity, color homogeneity, bruises, size, shape, and stem identification. The use of machine vision is also gaining interest for the determination of physical attributes of fruits and irregular-shaped objects, because it is a nondestructive method requiring image analyses and image processing procedures. Forbes and Tattersfield (1999) developed a combined machine vision and neural network technique for the estimation of pear volume from the 2-D digital images. Hahn and Sanchez (2000) developed an imaging algorithm to measure the volume of non-circular shaped agricultural products such as carrots. Sabliov et al. (2002) and Wang and Nguang (2007) used image processing techniques to compute the volume and surface area of axi-symmetric agricultural products. Lee et al. (2003) and Eifert et al. (2006) have adopted the machine vision approach and developed imaging systems for estimating the volume for irregular-shaped agricultural products using radial projections. Koc (2007) determined the volume of watermelon using ellipsoid approximation and image processing. Khojastehnazhand et al. (2009) have developed and tested machine vision and image processing for computing surface area and volume of axi-symmetrical agricultural products.

Computer-generated artificial classifiers that are intended to mimic human decision making for grading and product quality have recently been studied intensively. The online lentil color classification using a flatbed scanner with neural classifier developed by Shahin and Symons (2001) achieved an overall accuracy of more than 90%. Leemans et al. (2002) developed an on-line fruit grading system based on external quality features of two varieties of apples, Golden Delicious and Jonagold, using quadratic discriminant analysis and neural networks. The image grading was achieved in six steps: image acquisition; ground color classification; defect segmentation; calyx and stem recognition; defects characterization; and finally the fruit classification into quality classes. Both algorithms resulted in similar results (79% and 72%) for both varieties studied. Blasco et al. (2003) combined machine vision techniques with Bayesian discriminant analysis for online estimation of the quality of oranges, peaches, and apples, and evaluated the efficiency of these techniques regarding the following quality attributes: size, color, stem location, and detection of external blemishes.

The objective of this research was to develop an image processing method for determination of volume of citrus fruits such as lemon, lime, orange and tangerine. The method provides a valuable alternative to the traditional methods for measurement of volume of axi-symmetric agricultural products and can be used to design and develop sizing systems.

2. Theory

The actual volume of fruits can be measured by water displacement method (WDM). The WDM is one of the most common and simple means of measuring the volume of large objects such as fruits and vegetables (Mohsenin, 1970). The procedure is as follows: the fruit is first weighed on a scale and then dipped into water with a sinker rod. The weight of the displaced water is then calculated by subtracting the weight of the water-filled container from the weight of the container when it contains the fruit. The resulting value is then used to calculate the volume of the fruit by using (Mohsenin, 1970):

$$\text{volume (cm}^3) = \frac{\text{weight of displaced water (kg)}}{\text{water density (kg/cm}^3)} \tag{1}$$

Even though the WDM method is quite accurate, it is not ideal for objects that absorb water and for some products, this approach might be considered intrusive or destructive.The volume of fruits can also be computed numerically using image processing technique. The volume of a conical frustum can be calculated using equations that are commonly found in mathematics handbooks (Szirtes, 2006). Consider the 3-D representation of an axi-symmetric object (Fig. 1). One can divide the image of the object into a number of frustums of right cone. To increase the system accuracy, the lateral surfaces are assumed elliptical. Without loss of generality, these elementary cylindrical objects are assumed to be of equal pixel height, h (Fig. 1c). The total volume of the object under investigation (citrus fruits in this case) can then be computed by summing these elementary volumes. The required dimensional attributes are the top and bottom diameters and height of the frustum (di_1, di_2, h) as shown in Fig. 1b and c, respectively. The lateral or cross-sectional areas through the elliptical frustum (A_i and A_{i+1} in Fig. 1c) can be calculated accurately using the two perpendicular diameters (Fig. 1b) as measured by the two cameras. The expression for calculating the lateral surface area A_i is given by (Khojastehnazhand et al., 2009):

$$A_i = \pi \times \frac{di_1}{2} \times \frac{di_2}{2} \tag{2}$$

where di_1 and di_2 are the two perpendicular diameters (Fig. 1b). Once the lateral surface areas are obtained, the volume of each frustum (V_i) can be computed as:

$$V_i = \frac{A_i + A_{i+1}}{2} \times h \tag{3}$$

where A_i and A_{i+1} are, respectively, the top and the bottom cross-sectional areas, i and $i + 1$, of each frustum and h is the frustum pixel height, as shown in Fig. 1c. All frustums were assumed to have equal thicknesses.

The accuracy of estimated lateral surface area A_i and hence the volume V_i ($i = 1, 2, \ldots, n$) of each frustum (Eqs. (2) and (3), respectively) depend on the position of minimum and maximum diameters of the fruit's surface and the total number of segmentation (n). For the calculation of citrus fruits presented in this paper, a value of $n = 8$ is used throughout, to speed-up the calculation. However, for other axi-symmetric agricultural products with irregular surfaces such as peppers or carrots higher values of n is recommended.

Once the volume of each frustum is obtained, the total volume of the fruit can be calculated by adding them up (Khojastehnazhand et al., 2009):

$$V_{IP} \cong \sum_{i=1}^{n} V_i \tag{4}$$

where V_{IP} is the total volume of the fruit calculated by image processing (IP) method.

Recently, we have extended the fore-mentioned technique for computing the surface area of fruits. General expressions for computing the surface area of elliptical products can be found in Khojastehnazhand et al. (2009). Consequently, the volume and surface area of any irregular-shaped agricultural product such as citrus, peaches, melon, kiwifruit, and pear can be estimated by the proposed image processing technique.

The characterization results for various citrus fruits showed that the volume and mass parameters are highly correlated. Consequently, it seems beneficial to relate fruit mass to its volume and use regression equations to predict the weight of new citrus fruit given its volume and vice versa. Therefore, a simple procedure based on volume of assumed ellipsoidal shape (V_{IP}) is developed for mass modeling of citrus fruits.