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Digital Images Analysis on a Mobile Device to Estimate Surface Area and Volume of Mango Fruit (*Mangifera indica* L.)

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ABSTRACT

Objective: To develop a technique based on the partition method, to estimate the surface area and volume of mango fruit (*Mangifera indica* L. cv. "Ataulfo") using two digital orthogonal images, obtained and processed on a mobile device with the Android® operating system, segmented by different discriminants.

Design/Methodology/Approach: A technique was developed to estimate the surface area and volume of "Ataulfo" mango fruit based on digital images and was implemented directly on a smartphone with the Android® operating system. Three discriminants were evaluated for segmentation (red channel, green channel, and HIS color intensity) and applied in n=30 fruit. The precision and accuracy of the technique was determined.

Results: The surface area and volume of the fruit when estimated using the red channel presented a coefficient of variation of less than 2.0% in both variables and the estimation error was less than 3% for surface area and less than 5% for volume.

Study Limitations/Implications: This technique was limited to fruit with an elliptical cross-section and smooth surface.

Findings/Conclusions: The proposed technique is a non-destructive alternative to estimate the surface area and volume of "Ataulfo" mango fruit with a reasonable margin of error and can be implemented directly on an Android® device using only the red channel as a segmentation discriminant.

Key words: Android®, elliptical frustum, segmentation, smartphone.

INTRODUCTION

Mango (*Mangifera indica* L.) is a tropical crop of global importance. Mexico is the number one exporter and produces more than 50 cultivars. One of these is "Ataulfo", whose organoleptic and nutritional characteristics make it acceptable for the international market (Palafox-Carlos *et al*., 2012; Sáyago-Ayerdi *et al*., 2013).

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The size of horticultural products, in addition to being a variable for quality, affects physical properties such as surface area and volume. These properties are necessary for the study of physiological processes such as phenomena related to gas permeability, transpiration, and cooling (Goñi *et al*., 2007; Valle-Guadarrama *et al*., 2009).

The analysis of digital images has made possible the development of non-destructive methods for estimating surface area and volume of horticultural products. The best results were found with the use of a 3D scanner (Uyar and Erdogdu, 2009; Kelkar *et al*., 2011), infrared sensors (Wang and Li, 2014), and commercial software for computer-aided design (Goñi *et al*., 2007).

One alternative is the use of systems that only require a digital camera and a processing unit (Saltani *et al*., 2011). However, these systems have been applied in products with a regular shape such as: citrus, watermelon, melon or egg (Koc, 2007; Fellegari and Navid, 2011). In mango fruit, weight has been correlated to the sizes measured directly in digital images (Teoh and Syaifudin, 2007; Spreer and Müller, 2011). The availability of smartphones with cameras and a high processing capacity represents an alternative for estimating diverse variables such as: the color index and yield of citruses (Cubero *et al*., 2018) or the chlorophyll content (Vesali *et al*., 2017). Thus, it is possible to combine the analysis of digital images with the advantages of mobile devices to estimate the surface area and volume of "Ataulfo" mango fruit. For these reasons, the objective of this study was to develop a technique based on the partition method in order to estimate the surface area and volume of "Ataulfo" mango fruit using two orthogonal digital images obtained and processed on a mobile device with Android® operating system, segmented by different discriminants.

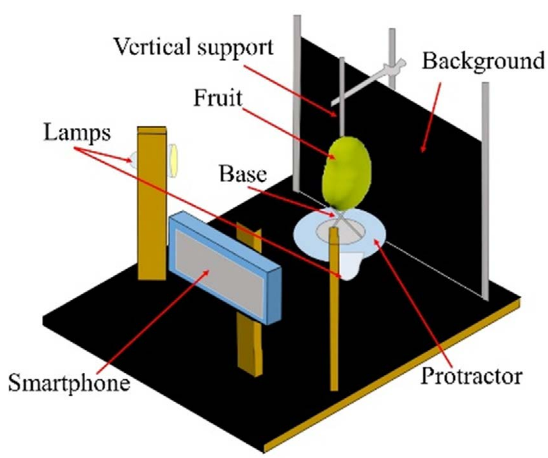

Figure 1. Image capturing system to estimate surface and volume of mango fruit.

MATERIALS AND METHODOLOGY

Plant material

This study was conducted in the Postharvest Physiology laboratory of Colegio de Postgraduados. Ripe mango (*Mangifera indica* L. cv "Ataulfo") fruit were used, acquired in the local market of Texcoco, Estado de México.

Capture conditions

Each fruit was placed on a revolving base, and two fluorescent lamps (28 W, 6500 K, D65 and 1747 lm, Promilight®, made in China) were placed 21.5 cm from the center of the fruit, angled at 45° against a black background. A smartphone (CellAllure Book2 model CAPHG28-01, Android® 4.4.2) was placed at 20.0 cm from the fruit to take a photo of the widest side of the fruit and another after turning it manually 90° (Figure 1).

Image capture method

The images were captured using the device's default photo application with the automatic settings, with a resolution of 640×480 pixels in the JPEG format at 24 bits. Each fruit was processed five times. In total, n=300 images were captured.

Preprocessing and grayscale image generation

A median filter with a 5×5 matrix was applied to the RGB images. Of the filtered images, three 8-bit images were generated in grayscale, based on: the red channel value (***RC***), the green channel value (***GC***), and the color intensity (***I***) of the HSI space (hue, saturation, and intensity) (Figure 2). The blue channel did not provide sufficient information for segmentation.

Segmentation of images in grayscale

The images were binarized using a local minimum (Gonzalez and Woods, 2007). Within the histogram, the local maximums were identified in the low intensity zone and in the high intensity zone. The threshold was determined as the local minimum between by the local maximums (Figure 3).

Analysis of digital images in grayscale

The grayscale images were processed and analyzed directly in the application for mobile devices, which was developed on Google's open source Android Studio 3.2.2 platform (Figure 4).

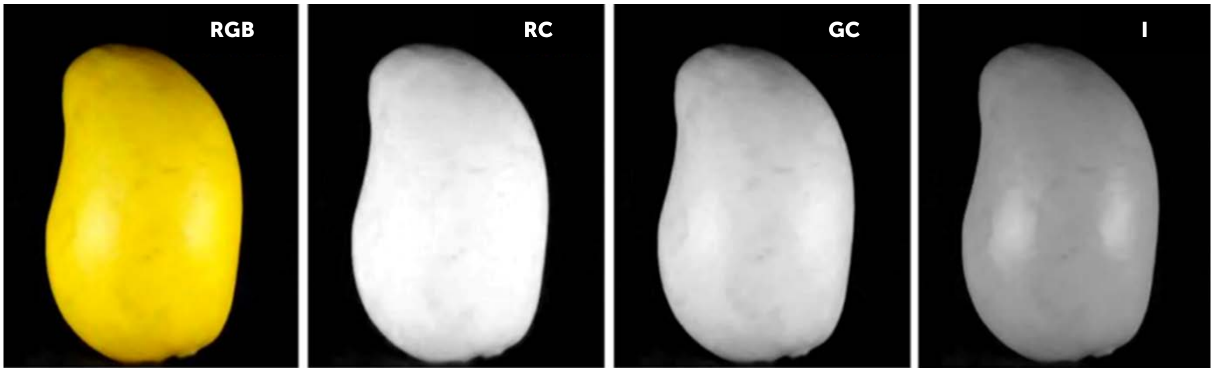

Figure 2. RGB image and grey scale images; red channel (RC), green channel (GC) and HSI color intensity (I).

Estimation of surface area and volume

The fruit was viewed as a group of elliptical frustums vertically overlapped and the lateral surface area and volume of each cone was estimated. According to Baldor *et al*. (1997), an elliptical frustum is characterized by the semi-major axis (*r*) and the semi-minor axis (*s*) in each of its bases, and its height (*h*). The values of *r* were obtained from the image taken at 0°, the *s* values were obtained from the image taken at 90° according to the number of pixels that corresponded to the fruit in each row, while *h* was kept constant at one pixel (Figure 5).

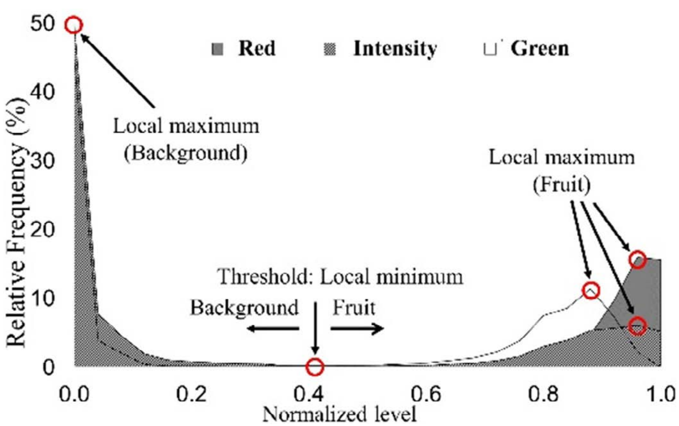

Figure 3. Histogram of the normalized values of the red channel, green channel, and HIS color intensity from the RGB image.

The surface area could be estimated using the sum of the lateral surface area of each cone, obtained as the mean perimeter of the bases multiplied by the generatrix (Equations 1 and 2) (Khojastehnazhand *et al*., 2009).

$$A_f = \frac{\pi}{2}\sum_{i=1}^{n-1}\left(r_i + s_i + r_{i+1} + s_{i+1}\right) * G_i$$

$$G_i = \left(h^2 + \left(\frac{r_i + s_i}{2} - \frac{r_{i+1} + s_{i+1}}{2}\right)^2\right)^{1/2}$$

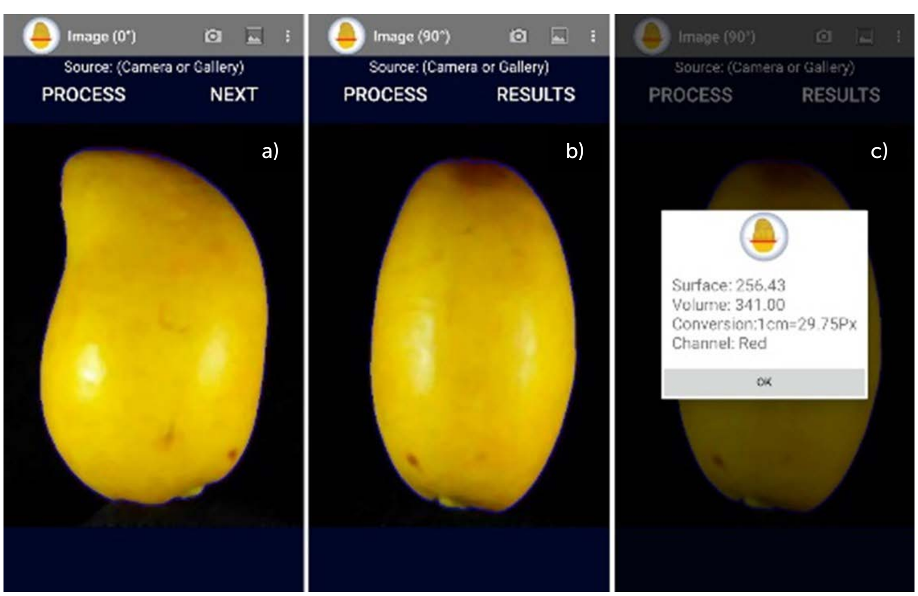

Figure 4. Android® application to estimate surface and volumen of mango fruit. a) and b) Contour identification on both fruit images (0° and 90°) and c) Results.

Where *i* indicates the row of pixels at the base of the cone; *n* is the total pixel rows of the fruit; *h* is the cone height (1 *Px*); G_i is the generatrix; and A_f is the surface area of the fruit (Px^2). Following Khojastehnazhand et al. (2009), the fruit volume was estimated as the sum of the volume of each cone, calculated as the average of the surface area of the bases multiplied by the cone height (Equation 3).

$$V_f = \frac{\pi}{2}\sum_{i=1}^{n-1}\left[\left(r_i * s_i\right) + \left(r_{i+1} * s_{i+1}\right)\right] * h$$

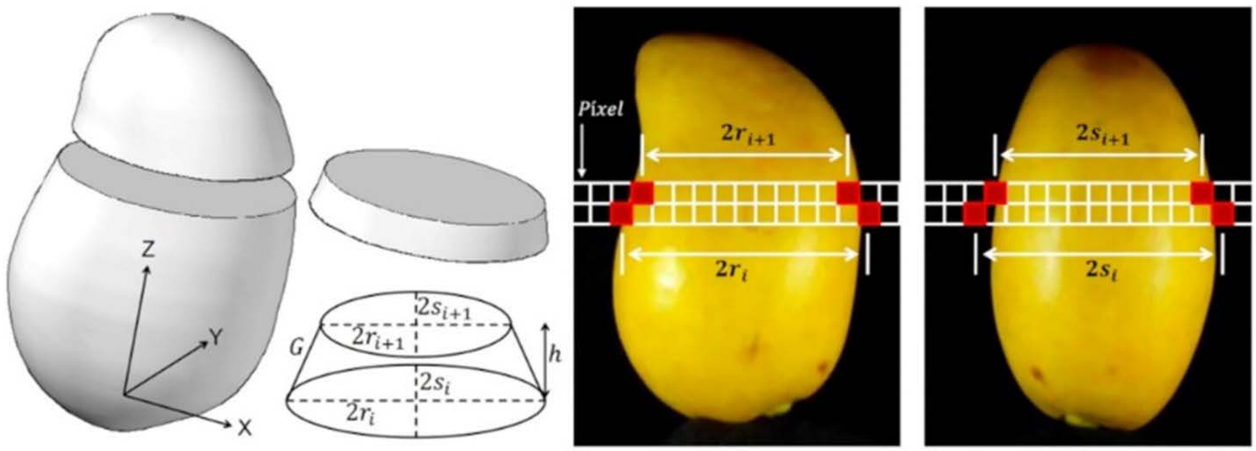

Figure 5. Mango fruit divided by elliptical frustums and variables of the frustum obtined from digital images.

Where *i* is the row of pixels where the cone's base was measured; *n* is the total pixel rows of the fruit; *h* is the height (1 *Px*); and V_f is the fruit volume, in Px^3.

Image calibration

A measuring stick was photographed in a vertical position, placed at the same distance as the fruit, and the spacing between the graduated marks was measured in the resulting image with the Image Tool 3.0 software (University of Texas Health Science Center at San Antonio). One pixel represented on average 0.0336 cm, and this value was used as a conversion factor to cm^2 and cm^3 for surface area and volume, respectively.

Measurement of reference surface area and volume of fruit

The fruit volume was measured using the water displacement method in a container (1200±1.75 mL). The fruit was placed inside the container, then 1000 mL of distilled water was added, previously measured in a 1000 mL volumetric flask, and the displaced liquid was collected using a 250 mL graduated cylinder.

To obtain the reference surface area, the pericarp was manually extracted from the fruit in vertical strips using a stainless-steel knife (Guillete®). The strips were digitalized with a scanner, model HP Scanjet 3770, and the surface area of each one was measured using the calibration technique (Figure 6).

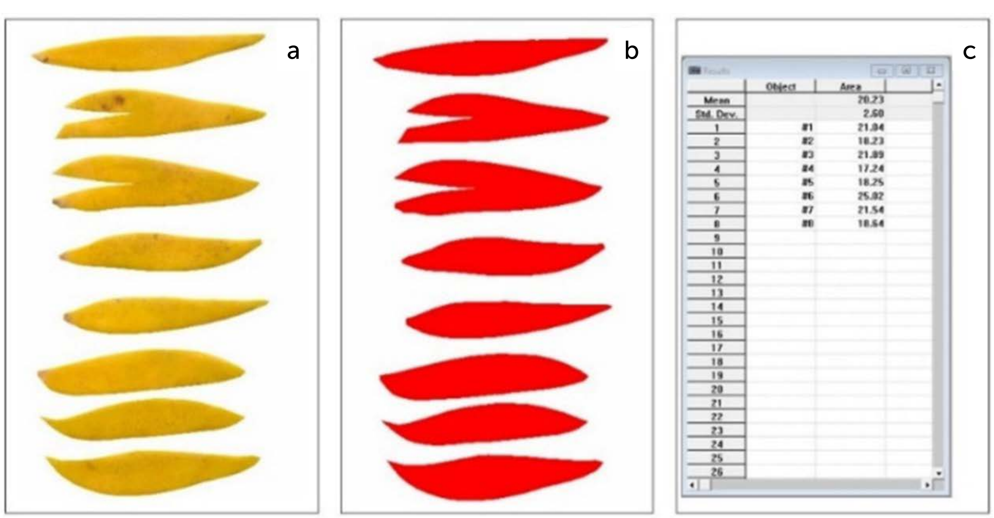

Figure 6. a) Mango fruit´s pericarp, b) segmented image y, c) individual surface

Data analysis

The technique's precision was determined in terms of the mean coefficient of variation, and its accuracy as the mean relative error (Equation 4). In addition, a simple regression analysis (Equation 5) was carried out. The data were processed with R-Project® within the R-Studio® interface.

$$Err(\%) = \left| \frac{x_0 - x_1}{x_0} \right| * 100$$

where x_0 is the value measured using the reference method (cm^2 or cm^3); and x_1 is the value estimated using the digital images (cm^2 or cm^3).

$$y = \beta_0 + \beta_1 * x + e$$

where y is the reference surface area or volume (cm^2 or cm^3); x is the surface area or volume of the fruit, estimated using the digital images; β_0 is the ordinate of the origin; β_1 is the slope; and e is the random error NIID (o, σ^2).

RESULTS AND DISCUSSION

Estimation of total surface area of the fruit

The surface area estimated using the digital images segmented using the red channel (***RC***) presented a lower standard deviation and coefficient of variation (3.07 cm^2 and 1.39%), while the greatest variation was found in the images segmented using color intensity (***I***) (Table 1). Sabliov *et al*. (2002) found lower values (0.32 cm^2) applying this method on spheres and lime fruit, but found higher values on lemon (3.7 cm^2) and peach (3.6 cm^2). This could possibly be due to the difficulty in placing the fruit in the same position.

In all cases, the fruit surface area was overestimated (Figure 7). However, the greatest accuracy was obtained from the images segmented using the red channel (***RC***), with a relative error of 2.19%, while the images segmented using color intensity (***I***) had 2.36% error; this rise in error could be caused by the blue channel, since it did not provide information individually for segmentation. Sabliov *et al*. (2002) attributed overestimation to the threshold method, and in this case, it can be attributed to the pericarp contracting after being removed from the fruit.

The estimation error was found in what was reported for other products such as eggs with 0.82% using a 3D scanner (Uyar and Erdogdu, 2009), limes with 2.95%, and peaches with 6.0% using image processing (Sabliov *et al*., 2002).

The determining coefficient was 0.97 in all cases (Table 1) and is close to the values reported for strawberry (0.96) using 30 digital images (Eifer *et al*., 2006), for banana (0.97) using a model that obtains geometric parameters from digital images, and orange (0.92) using two orthogonal images (Khojastehnazhand *et al*., 2009).

Estimation of fruit volume

The greatest accuracy in volume estimation was obtained from the images segmented using the red channel (***RC***) with a standard deviation of 4.88 cm^3 and a variation coefficient of 1.70%. These results are greater than those reported in spheres (0.07 cm^3), egg (4.0 cm^3), and lime (3.4 cm^3), but less than those reported in lemon (6.6 cm^3) and peach (4.8 cm^3) by Sabliov *et al*. (2002).

The volume obtained by this technique was underestimated by less than 5.0% (Table 2 and Figure 8). The error in volume estimation for diverse products was: 2.0% in apple (Goñi *et al*., 2007), 2.6% in mandaris (Khojastehnazhand *et al*., 2010), 3.5% in egg (Uyar and Erdogdu, 2009), 3.7% in onion (Wang and Li, 2014), 4.56% in cucumber, and up to 7.8% in watermelon (Koc, 2007).

The coefficient of determination (R^2) found in this study was 0.93 for the red channel (***RC***) and 0.94 for the other two discriminants. These values are similar to those

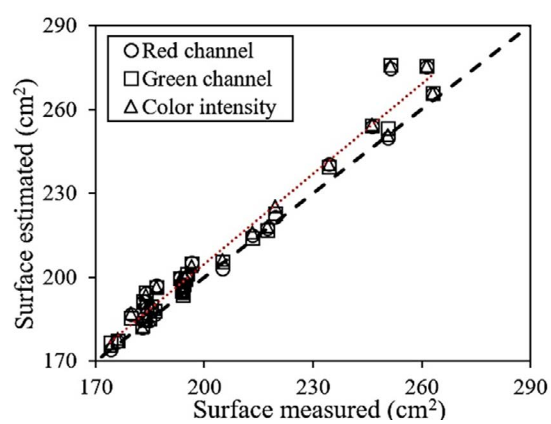

Figure 7. Surface of 'Ataulfo' mango fruit estimated by digital image analysis using different discriminants for segmentation.

Table 1. Surface of mango fruit estimated by digital image analysis. Standard deviation (*sd*), coefficient of variation (*C.V.*), relative error (*Err*), intercept (β_0), slope (β_1) and coefficient of determination (R^2).

Discriminant	*sd* (cm^2)	*C.V.* (%)	*Err* (|%|)	β_0 (P)	β_1 (P)	R^2
RC	3.07	1.39	2.19	14.57 (0.029)	0.91 (<0.001)	0.97
GC	3.34	1.50	2.32	14.95 (0.019)	0.91 (<0.001)	0.97
I	3.39	1.53	2.36	14.59 (0.019)	0.91 (<0.001)	0.97

Discriminant: *RC*: Red channel; *GC*: Green channel; *I*: HSI color intensity.

Table 2. Volume of mango fruit estimated by digital image analysis. Standard deviation (*sd*), coefficient of variation (*C.V.*), relative error (*Err*), intercept (β_0), slope (β_1) and coefficient of determination (R^2).

Discriminant	*sd* (cm^3)	*C.V.* (%)	*Err* (|%|)	β_0 (P)	β_1 (P)	R^2
RC	4.88	1.70	4.73	30.34 (0.013)	0.92 (<0.001)	0.93
GC	5.03	1.74	4.71	28.56 (0.019)	0.92 (<0.001)	0.94
I	4.95	1.73	4.72	29.46 (0.015)	0.92 (<0.001)	0.94

Discriminant: *RC*: Red channel; *GC*: Green channel; *I*: HSI color intensity.

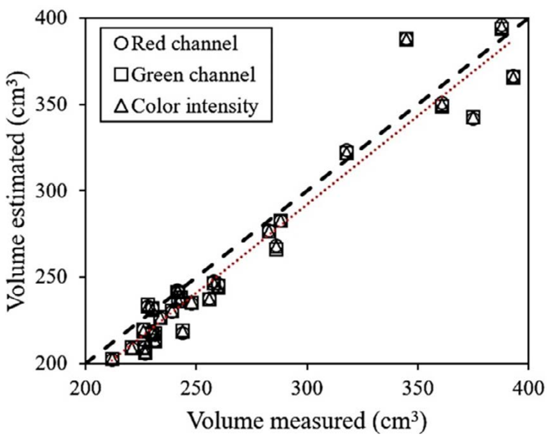

Figure 8. Volume of of 'Ataulfo' mango fruit estimated by digital image analysis using different discriminants for segmentation.

reported for mandarin (0.96) (Khojastehnazhand *et al.*, 2010), orange (0.99) (Khojastehnazhand *et al.*, 2009), onion (0.96 to 0.98) (Wang and Li, 2014), and apple (0.99) (Goñi *et al.*, 2007).

CONCLUSION

The proposed technique in this study is a non-destructive alternative to estimate the surface area and volume of "Ataulfo" mango fruit with a reasonable error margin and can be implemented directly on an Android® device using the red channel as the only discriminant for segmentation.

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