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A new method for estimating surface area of cylindrical fruits (zucchini) using digital image processing

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Abstract

Estimation of surface area and volume of agricultural products are considered as important factors in optimization of storage conditions, packaging, transportation, water adsorption/desorption, heat, pesticides and also their breathing. The objective of this study was to establish a method to obtain non-destructive measurement of surface area of cylindrical fruit like zucchini (*Cucurbita pepo*) using image processing technique. In this approach, measuring surface area was performed by a scanner set. Before peeling the fruit off, the external surface area of zucchini was imaged by rolling it on the scanner's screen. Then, the external surface area was calculated using image processing technique. In order to evaluate the accuracy of method, the results were compared with the usual measured skin surface area after peeling (actual value) in the same condition. The results showed that the precision of this new method is significantly high (R^2= 94.43). The mean and standard deviation of the surface area differences between the two methods were 5.81 cm^2 and 0.13 cm^2, respectively. The Bland-Altman approach was also considered to be satisfactory. The results showed that image processing method was suitable for surface area estimation of almost all zucchini sizes. Furthermore, all the process (photography and image processing) was performed in less than 6 seconds. The area of cylindrical fruits can be measured nondestructively, quickly, and precisely using the applied image processing technique, providing a hardware to scan external surface area of crop.

Keywords: Machine vision, Scanning, Sorting and Grading, Summer squash.

Abbreviations: A, B_Structure element; B_Blue; RBG_Red, Blue, Green color space; G_Green; GUI_Graphic User Interface; i_ Horizontal components of pixel; j_Vertical components of pixel; P_Result of statistical analysis; P(i,j)_image related to RGB component; Q(i,j)_Resulting image in "Subtract" function; R_Red; µ_Average; σ_Coefficient of variation.

Introduction

According to Soltani et al. (2011), determination of surface area is beneficial in prediction of both drying rate and time of drying. In addition, measuring fruit surface area is necessary for quality assessment of damages that usually occur by insects and microorganisms (Bovi et al., 2002). This attribute, as one of the most important parameters in the different stages of plant growth, is used to determine the relation between the fruit surface area and the period of growth. According to Nascimento (2008), value of summer squash as an agricultural product in the warm season, is related to physical properties of fruits. It has different cultivars such as straight neck, crookneck, semi-crookneck, and zucchini squash. Despite the existence of difficult and destructive methods for precise measurement of fruit surface area, there are different approaches such as using planimeter, and geometrical methods to estimate the relation of this parameter with length, width (diameter) or weight of fruits. In recent years, researches have tried to find rapid and non-destructive techniques to measure the physical attributes for industrial operations such as fruit sorting, quality grading and so on. Different mathematical and numerical methods have been applied to explore new methods to measure the surface area. Nowadays, machine vision is the most effective tool for external feature measurements such as color intensity, color homogeneity, bruises, size, shape and stem identification (Forbes and Tattersfield, 1999; Jafari et al., 2006; Lee et al., 1999; Lorestani et al., 2006). Sabliov et al. (2002) used an image processing algorithm to determine surface area of axisymmetric agricultural products. Wang and Nguang (2007) used the methodology developed by Sabliov et al. (2002) to measure the surface area of agricultural products. They created a representation of fruit product with a set of elementary cylindrical objects and estimated the volume and surface area by summing up the elementary volumes of individual cylinders. Both Sabliov et al. (2002) and Wang and Nguang (2007) reported that the method successfully estimated the surface area of lemons, limes and peaches. Bovi and Spiering (2002) estimated peach palm fruit's surface area using Allometric relationships. They used digital camera for surface area measurements. Their results showed a good correlation with gravimetry approach (about 98%). Eifert et al. (2006) predicted surface area of raw products through measuring their weights. They developed this method by using image processing technique and estimated external surface area and calculated surface area values. This method provided high repeatability for all of the fruits. Soltani et al. (2011) calculated the surface area and physical properties of banana. They supposed the banana shape as oval. They measured the surface area of banana using mean diameter of the fruit. Result of regression estimation showed that the measured surface area had high correlation with ellipse surface. Hryniewicz et al. (2005) developed a contactless system for 3d surface modeling. This system used two internet cameras with a slide projector as an independent light source. The methodology is based on an assumption that most of the fruits have circular cross section. The device accuracy was checked with 100 apples with known maximum diameters, which were classified with 100% success. As mentioned, in all previous studies, the surface area of fruits has not been measured directly. In other words, most of the presented approaches models are between surface area and weight. The objective of this research was to represent a rapid, simple and nondestructive approach to measure area of cylindrical fruits using a conventional scanner with image processing technique.

Results

Evaluation of RGB components in samples

In color components evaluation, gray levels of RGB (Red, Green and Blue) profiles from images were obtained. Fig 2. demonstrates that the gray level of green component is higher than the other components. Moreover, the gray level of blue component is lower than the other components. In profile of background, it is apparent that the R and B components have little difference (Fig 3a), whereas this difference between B and G is considerable. Fig 3.b indicates that small difference between B and G, subtracted from the B-G, provides the best result. This information can help to extract the zucchini images from the background.

Area measurement

The area values of rolling (as predicted values of image processing) vs. peeling (as actual values) are shown in Fig 4. The result data in both methods based on Kolmogorov-Smirnov test had normal distribution (P=0.3851 for peeling method and P=0.3106 for rolling method). Average and standard deviations of difference of both obtained data were calculated as 0.13 cm^2 and 5.81, respectively. Moreover, t-paired analysis, indicated in Table 1, shows that both measured surface area values show no significant difference.

Algorithm analysis

The t-paired test was performed on the credit cards with specified area. The results showed no significant difference between predicted data with image processing and actual data. The results demonstrated the comparison between data of rolling and peeling methods. The linear regression was passed through data with R^2=0.9776.

Discussion

Bland-Altman's graph was drawn to compare the rolling (image processing) and peeling surface (actual) area values. As shown in Fig 5, 95% of the surface area differences were expected to lie between $\mu-1.96\sigma$ and $\mu+1.96\sigma$, known as 95% limits of agreement (Bland and Altman, 1999). The 95% limits of agreement for comparison of surface area determined with peeling and rotating were calculated to be -11.52 and 11.26 cm^2. Fig 5. demonstrates that conformity of rolling and peeling data are not under the influence of zucchini fruit's size. Meanwhile, it is presumable that algorithm error is low, because most of data are close to the average. ID cards with specified area were processed and then were predicted by software and were compared with real area values. The trend line of predicted vs. actual data shown an excellent correlation of R^2= 0.9659. The color components evaluation in images showed that subtracting the blue component from green is suitable for feature extraction. The result of paired t-test by Khojastehnazhand et al. (2009) experiment revealed a value of 0.8371 that is lower than results obtained from this study. Moreover, the correlation of predicted vs. actual data was reported to be low when compared. Meanwhile, the defined approach takes less time for information processing due to lack of simulation and process of three-dimensional shapes on a given computer. The represented model by Soltani et al. (2011) was able to compute the banana surface area with R^2= 0.964. Furthermore, this value showed low precision of their method

Table 1. Results of t-paired test on obtained data from both rolling and peeling approaches.

Parameters	Fruits' surface area
Paired t-test	0.892
95% confidence interval for the difference in means (cm^2)	-1.73, 1.98*

*This means that, given the variance was observed, 95 out of 100 was repeated comparisons between the two methods would have mean differences in the interval described. As data in table, if this confidence interval includes "0" (-1.73 to +1.98) then we can claim the two means are not significantly different.

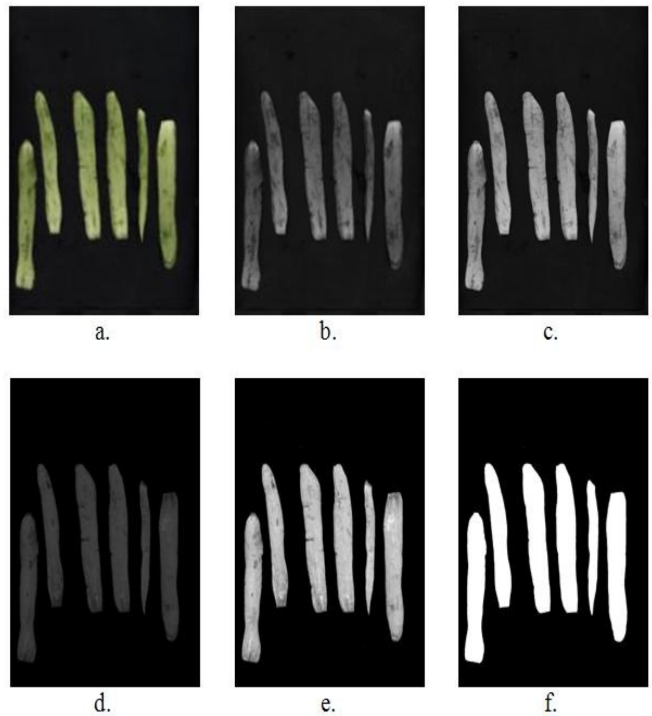
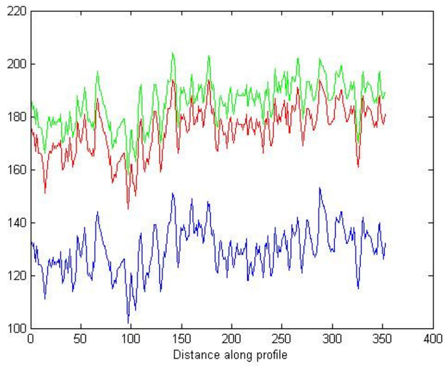
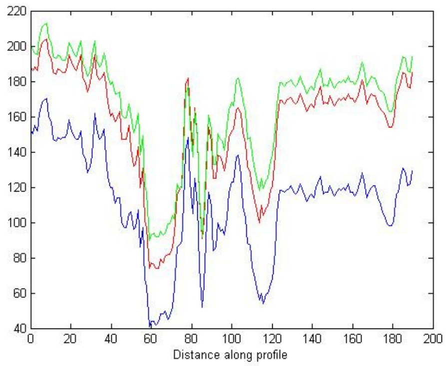


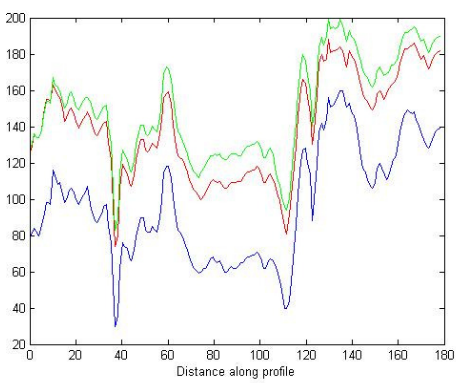
Fig 1. The image processing result. (a) The captured image of peeled skin of a zucchini, (b) blue channel, (c) green channel, (d) blue and green difference, (e) increase resolution, and (f) binary image.



(A)

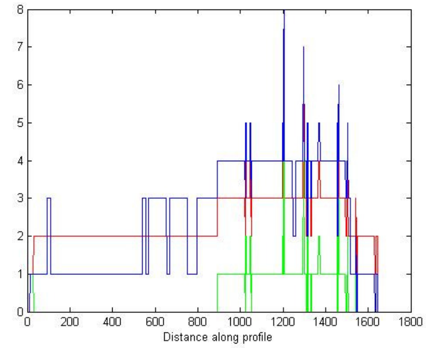


(B)

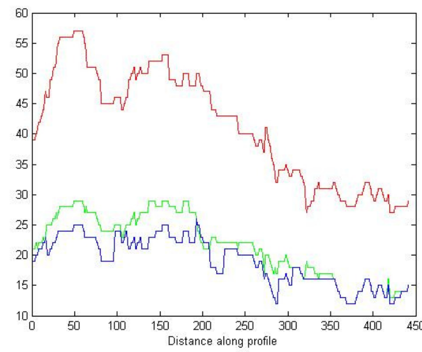


(C)

Fig 2. Grayscale profiles from (a) healthy section, (b) scratched section, and (c) defected section, of zucchini.



(A)



(B)

Fig 3. Grayscale profiles from (a) background, (b) tester's hand.

compared with the given approach in this study. Consequently, these comparisons demonstrate the credibility of our method compared to the literature in computer simulation of fruit.

Time analysis

The scanning process along with the rolling of fruits on scanning surface took about 5 or 6 seconds. Additionally, time of image analysis by software is 300 milliseconds. Consequently, total time of the process to measure surface area of a zucchini fruit took less than 6 seconds. It is very fast compared to previous works. In tape approach, covering of fruit's surface by tape take about 2 or 3 minutes, depending on fruit size. According to Khojastehnazhand et al. (2009), this time may increase to 5 minutes if considered manual calculations. With a simple calculation it can be found that measurement of 40 fruits' surface area by this novel approach is possible during the same time. Furness et al. (2002) found that there is no considerable difference amongst the three nondestructive methods (linear method of Baugerod, shrink-wrap replica, and image processing) for measuring surface area of some vegetables such as carrot and sugar beet. But image processing method for cucumber and carrot samples showed higher values compared to others. The result values obtained from measuring surface area by image processing method were higher than peeling method. The reason of this matter was perhaps because of low symmetry of zucchini around its central axis. Wang et al. (2007) measured external surface area of some fruits using image processing method and analyzed the results of t-paired. They observed that the measured surface area has considerable difference with real surface area. This result shows that imaging method for circular and non-cylindrical fruits does not seem proper method. This result was reported by Rashidi et al. (2007). However, the results of present study prove that image processing method can measure the surface area of cylindrical fruits more accurately. Moreover, the difference between the result data obtained from image processing method and the actual data were analyzed by Friedman test. Significant level of this test was more than 0.05 (P=0.206). There was no difference between these two methods.

Materials and methods

In order to compare data obtained from two methods of measuring surface area and also studying the accuracy of provided model, 40 samples of zucchini fruits were assessed separately. Zucchini fruits have regular and cylindrical shape i.e. their volumes are distributed uniformly.

Image capturing

Photography system was prepared from an ordinary "Genius ColorPage-HR8" scanner along with the installed software in Windows XP. The fruits were rolled on glassy scanning surface with scanner lamp speed simultaneously. During experiments it was perceived that two points were important for increasing accuracy. First, in order to omit overlapping and recognizing one revolution rolling of fruits, a line was drawn axially on fruit's surface. During the scanning procedure, to prevent slow or fast rolling of fruits, the scanner's lamp under the fruit should not be seen from top view. For obtaining the accuracy of the presented approach, after each scanning, actual surface area on the same conditions was determined, the sample was peeled and skin slices put without overlapping on scanning surface. All images were prepared in resolution of "160" dpi and scale of "1275×1753" pixels. The image preparing process was performed for 40 zucchini samples.

Image processing

All prepared images were imported to "Adobe Photoshop CS4" software (Adobe System Inc.). As shown in Fig 1., the outside part the two lines (it related to rolling more than a revolution) was removed, and it was converted to background color. In order to process the images, a Visual Studio program was written by "Visual Basic 2008" (Microsoft Inc.) language. This algorithm was prepared with graphical user interface (GUI) to create simpler environment. The used functions in this software were similar to the MATLAB software and the results were equal. Resolution of the images was improved by domain stretching of intensity values using "Contrast Stretch", also known as normalization algorithm. The result was an image with higher contrast due to its feature to convert a narrow range of input levels to a vast range of output ones. At the next step, red, blue and green components of RGB images that were previously taken from zucchini were extracted. Then, two images resulted of green and blue channel (original image and covered or substituted image) with the same size and pixel frame were selected. A new image was created which its pixels were equal with the difference of the same component pixel values of both input images. The output pixels are made from:

$$Q(i,j) = P_1(i,j) - P_2(i,j) \qquad (1)$$

Where, Q(i,j) is the resulting image, $P_1(i,j)$ is the image related to green component and $P_2(i,j)$ is the image related to blue component.

The images should be blurred to remove tiny appendages in the thresholding stage. The images were converted to binary image based on a specific threshold value. With a trial and error method, the different values were selected for threshold.

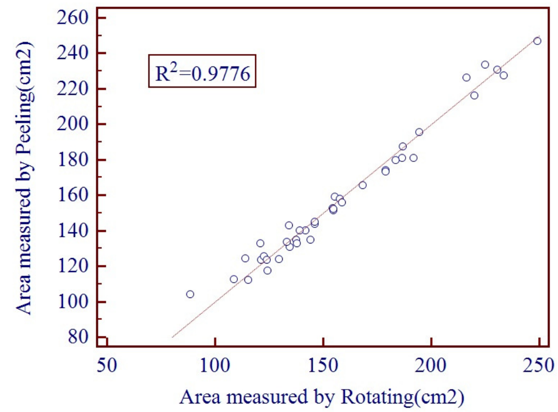


Fig 4. The result of comparison between estimated surface area values by image processing method and peeling method (R^2=0.9776).

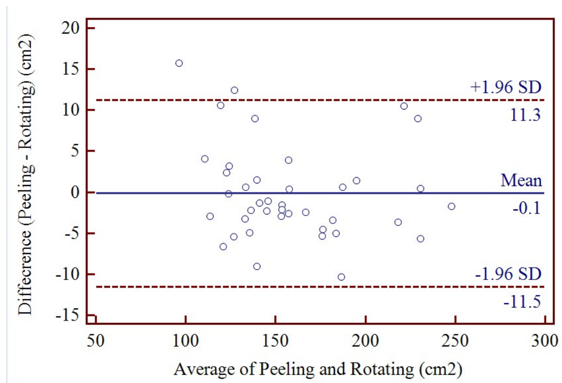


Fig 5. Bland-Altman plot for a comparison of zucchini surface area measured through rotating method vs. peeling method. The outer lines indicate the 95% limits of agreement (-11.52, 11.26) while center lines show the average difference (-0.13 cm^2). Consequently, it is expected that in 95% of cases, the measured surface area was equal for both image processing and peeling methods.

The optimum value obtained as 32. Due to the interactive software environment (i.e. the operator is observing the results immediately) by GUI controller, this method was suitable and useful. All remained pixels with the intensity lower than threshold value were converted to black pixels.

A "Dilatation" along with "Erosion" was applied on the images. Implementation of these acts on the binary images is connected or filled objects that are close together.

$$A \cdot B = (A \oplus B) A \theta B \qquad (2)$$

$$A \oplus B = \left\{ z \middle| \left(\hat{B}\right)_z \cap A \neq \phi \right\} \qquad (3)$$

$$A \Theta B = \left\{ z \middle| \left(B\right)_z \subseteq A \right\} \qquad (4)$$

Where, ϕ empty set and B is the structure element. In the geometry viewpoint, $A.B$ is the union complement of all transferred B that do not overlap with A. "Close" function makes the region perimeter smooth through connecting small cracks or filling long narrow distances and small orifices (Gonzales and Woods, 2004). These acts were applied on images in order to fill small points on zucchini surface like black spots, dirt or mud that covered fruit's surfaces. At the end of process, the objects were extracted from binary images, and then their specifications were calculated such as pixel area (number of pixels in the object region) and calibrated area (number of pixels in the object region × ratio of actual to predicted values) in cm^2. In the other approach, the images prepared from the fruit skin slices after peeling were processed with the previous algorithm. In these images, like Fig 1, the whole surface area of fruits, as the actual surface area, were determined by summation of area values of all skin slices.

In order to model data calibration for evaluation of the algorithm accuracy, 16 credit cards with specified area (ID-1, according to ISO/IEC 7810 standard) were prepared and scanned. A correction coefficient was defined as calibration of predicted area values related to the actual value. The scanner coefficient was obtained from the ratio of actual to processed area values of standard surface of credit cards. For evaluation of model accuracy, Bland-Altman method and t-paired test were used as standard.

Conclusions

A specific algorithm was represented to determine surface area of zucchini fruits. This approach can be developed for the other cylindrical fruits such as cucumber, eggplant, melon. The statistical analysis on data illustrated that difference of the presented method and actual data values is not significant at the level of $P<0.05$. Moreover, Bland-Altman analysis demonstrates that size of fruits (volume) does not have a meaningful influence on external surface area. With hardware development, a rotational axis can be fixed on the fruit ends and move fruit parallel to the scanner lamp simultaneously. This system can be industrialized for the grading and sorting agricultural crops.

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