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Original Article

Measuring Geometric Mean Diameter of fruits and vegetables using Light Sectioning Method

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Abstract

This paper proposes a new technique to measure the geometric mean diameter (GMD) of selected fruits and vegetables calculated from a three-dimensional (3D) image by computer vision system (CVS). From a single view of the image data a linear laser light projects onto the top of the sample through the center in order to mark the measurement points. The planar metrology and the measurement between planes are employed to calculate the width and height of the samples. Homography transformation and cross ratio are the mathematical parameter applied to calibrate the image data to real world distance (in metric system). GMD of sample can be calculated from a single view of the image with this technique. The percentage of error of GMD obtained from CVS compared with GMD measurements using vernier calipers is approximately 0.03-5.14 depending on the shape of the objects. However, it can be concluded that this technique is worthwhile for measuring GMD of symmetrical objects.

Keywords: computer vision, geometric mean diameter, fruit, vegetable

1. Introduction

A computer vision system has been researched and developed since 1920s. It is a non-destructive method that has been applied in several areas, for example, medicine, biology, satellite communication, commercial documents, archaeological data, forensic data, industrial processing (O'Leary *et al.*, 2005). It is also used in the application of agriculture. The geometric mean diameter (GMD) of fruits and vegetables is one of the important physical properties for grading the size of samples. There are many articles reporting about a classification of color and size of fruits and vegetables using the computer vision and image processing; however, most of them have used the 2D image (Brosnan and Sun, 2002). The objective of this paper is to present the measurement of the GMD of objects from its three-dimensional image captured with a camera in a single view.

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2. Theory

2.1 Geometric mean diameter

GMD can be calculated from the equation as shown in Figure 1 (Mohsenin, 1980) where a = longest intercept, b = longest intercept normal to a, and c = longest intercept normal to a and b. The intercepts need not to intersect each other at a common point.

2.2 Structured light sectioning

The light sectioning method is a well-known measurement technique for optical determination of object sections

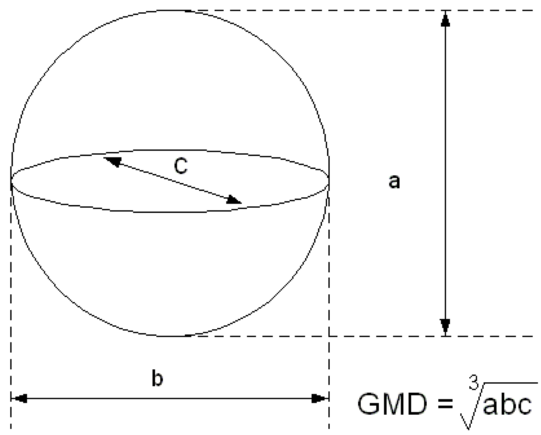

Figure 1. Geometric mean diameter.

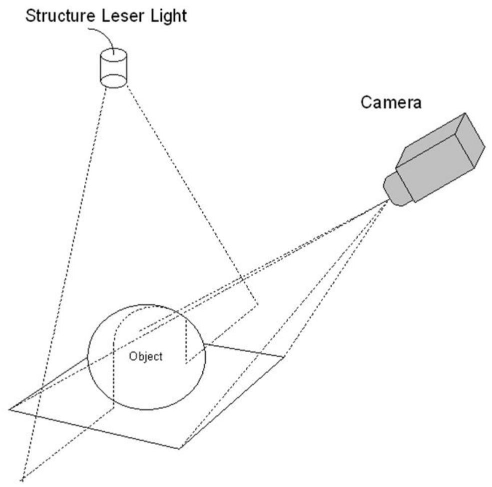

Figure 2. Structured laser light.

(O'Leary *et al.*, 2005). A light plane is projected onto the object from one direction. Most commonly a laser serves as a light source. The three-dimensional image is captured with a camera while the top of the object is cross-sectionally projected with a linear laser light. The position of the samples, light source, and camera are set as shown in Figure 2.

2.3 Planar metrology

The planar metrology (O'Leary *et al.*, 2005) is the method to measure the geometry on a plane. It is necessary to know the real world data being the reference coordinate. A point in the plane is defined in homogeneous coordinates as

$$p = \begin{bmatrix} x \\ y \\ w \end{bmatrix} \tag{1}$$

In two dimensions, the homography projection H of p to a point p' on an other plane can be formulate as

$$p' = Hp \tag{2}$$

$$p' = \begin{bmatrix} x' \\ y' \\ w' \end{bmatrix} \tag{3}$$

where p' and p are the homogeneous coordinates of the corresponding points p (pixel coordinates) and p' (real-world), and H is a homography matrix as,

$$\begin{pmatrix} x' \\ y' \\ w' \end{pmatrix} = \begin{pmatrix} h_{11} & h_{12} & h_{13} \\ h_{21} & h_{22} & h_{23} \\ h_{31} & h_{32} & h_{33} \end{pmatrix} \begin{pmatrix} x \\ y \\ w \end{pmatrix} \tag{4}$$

One of the nine parameters within H can be interpreted as scaling. The remaining eight entries can be determined by using 4 points given in the two planes. A linear algorithm can be derived by expanding Equation (4) for a given point correspondence and normalizing with respect to the homogeneous component to yield,

$$x_i' = \left[\frac{h_{11}x_i + h_{12}y_i + h_{13}}{h_{31}x_i + h_{32}y_i + h_{33}} \right], y_i' = \left[\frac{h_{21}x_i + h_{22}y_i + h_{23}}{h_{31}x_i + h_{32}y_i + h_{33}} \right] \tag{5}$$

In this case, the point correspondences are assumed to be image coordinates, hence homogeneous component $w_i = w'_i = 1$ then the homography matrix can be rewritten as follows:

$$\begin{pmatrix} x_1 & y_1 & 1 & 0 & 0 & 0 & x'_1 x_1 & x'_1 y_1 & x'_1 \\ \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \\ x_4 & y_4 & 1 & 0 & 0 & 0 & x'_4 x_4 & x'_4 y_4 & x'_4 \\ 0 & 0 & 0 & x_1 & y_1 & 1 & y'_1 x_1 & y'_1 y_1 & y'_1 \\ \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \\ 0 & 0 & 0 & x_4 & y_4 & 1 & y'_4 x_4 & y'_4 y_4 & y'_4 \end{pmatrix} \begin{pmatrix} h_{11} \\ h_{12} \\ h_{13} \\ h_{21} \\ h_{22} \\ h_{23} \\ h_{31} \\ h_{32} \\ h_{33} \end{pmatrix} = \begin{pmatrix} 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \end{pmatrix} \tag{6}$$

The solution of the homography matrix can be determined a linear equation system. Singular value decomposition (SVD) is a least square estimation that can be applied on this matrix to find the non trivial solutions of the homography. Then the real world coordinate can be calculated using the multiplication of matrix *H* and *p*.

2.4 Measurement between planes

A measurement between planes (Criminisi *et al.*, 2000) was applied to measure the height of a sample. The reference platform (A4 or A5 paper) is a rectangular shape that can be obtained a set of planes being parallel as shown in Figure 3. This technique can measure relative distances between planes. The cross ratio is determined from the relative distance between the camera point and a vertical vanishing point. Knowing the absolute distance (reference object) of an object that lies on the same plane is a requirement to measure the height of the sample. Figure 4 shows the relative distance on the plane and the camera point calculated from two vanishing points from the reference rectangular platform. The vertical vanishing supposes to be a point at infinity. The cross ratio R can be formulated as,

$$R = \left(\frac{d(x',c)d(x,v)}{d(x,c)d(x',v)} \right) \quad (7)$$

$$\frac{z}{z_c} = 1 - R \quad (8)$$

where Z is the absolute distance and Zc is the distance from camera to the plane. The calibration process of this measurement must know the real world distance of Z and then the Zc can be obtained. The next step is to determine the height of the sample from knowing of Zc.

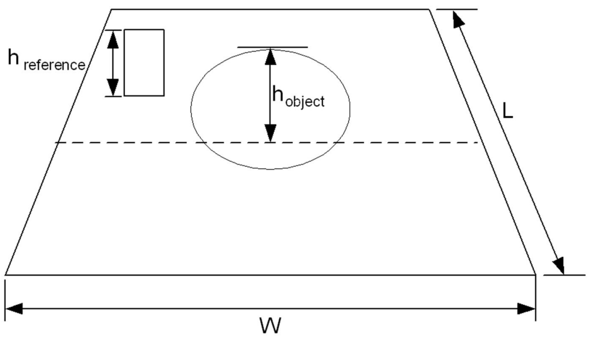

Figure 3. The reference platform.

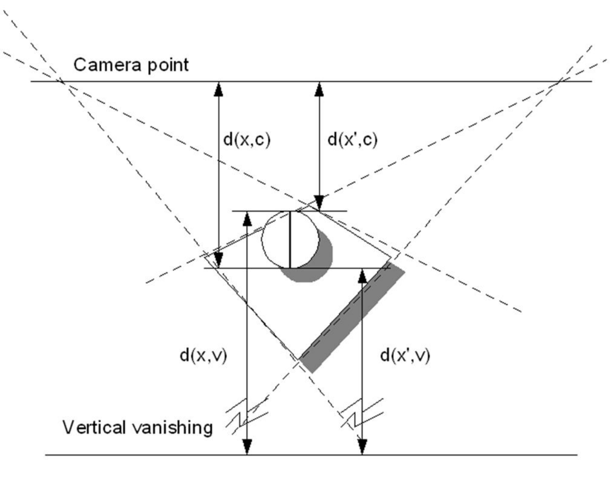

Figure 4. Relative distance on the planes.

3. Materials and Methods

Experiments were performed on measuring the dimensions of a selected fruit and vegetable by off-line image processing. The proposed technique was used to measure GMD of three sizes (large, medium, and small) of an apple, orange, and lime. A program was written in MATLAB version 6.5 to process the data. A digital camera (Olympus C-750, 4.0 million pixels, optical zoom 10x) was used to capture an image of each object. GMD calculated from the computer vision system was then compared with GMD measured with vernier calipers. Ten replicates were done in each test.

A linear laser diode performing structured light is used to define the projective points on the object as shown in Figure 5. A sample was put on the same plane with a known size of reference object and captured a 3D image in a single view with a digital camera. Planar metrology and the distance between two planes were applied to determine the width and height of samples. Consequently, the GMD can be calculated from a single image.

4. Results and Discussion

Table 1 presents the ratio of b/a, c/a, and GMD of an apple, orange, and lime measured with vernier calipers, GMD measured from CVS, and the percentage of error of GMD_{CVS} compared with GMD_V. The GMD of the apple is about 8.2 mm for large size, 7.8 mm for medium size, and 6.3 mm for small size. The GMD of the orange is about 6.7 mm for large size, 5.7 mm for medium size, and 4.5 mm for small size. The GMD of lime is about 4.8 mm for large size, 3.8 mm for medium size, and 3.3 for small size. From the results, it can be observed that GMD can be a parameter used to classify the grade of a sample determined by size.

The computer vision technique in this paper is capturing a 3D image of an object in a single view. The width (a) and height (c) of an object was calculated from the recorded image (Figure 4). In this study, the shape of the sample was assumed to be symmetry; therefore, ‘b’ value

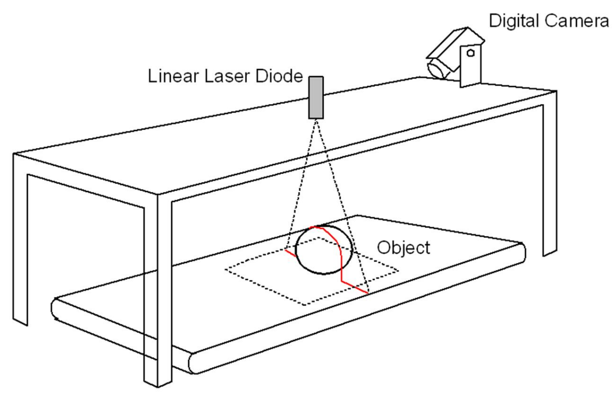

Figure 5. Structured laser light projected on an object.

Table 1. Diameter of object measured with vernir calipers and computer vision system technique

Size		Apple					Orange					Lime				
				Diameter of object					Diameter of object					Diameter of object		
		ratio b/a	ratio c/a	GMD_V	GMD_{CV}	Error (%)	ratio b/a	ratio c/a	GMD_V	GMD_{CV}	Error (%)	ratio b/a	ratio c/a	GMD_V	GMD_{CV}	Error (%)
Large	1	0.97	0.91	8.17	8.32	1.81	0.99	0.77	6.74	6.74	0.03	0.93	0.80	4.79	4.88	1.94
	2	0.98	0.85	8.29	8.50	2.40	0.97	0.79	6.64	6.67	0.41	0.98	0.82	4.64	4.72	1.59
	3	0.99	0.90	8.45	8.59	1.69	0.94	0.79	6.64	6.82	2.64	0.97	0.87	4.93	4.91	0.43
	4	0.94	0.81	8.27	8.52	2.94	0.97	0.77	6.72	6.81	1.37	0.97	0.83	4.91	4.93	0.28
	5	0.95	0.77	8.27	8.39	1.42	0.99	0.73	6.55	6.58	0.48	0.98	0.85	4.74	4.75	0.35
	6	1.00	0.85	8.25	8.39	1.58	0.94	0.75	6.76	6.97	3.13	0.97	0.84	4.81	4.79	0.41
	7	0.94	0.86	8.29	8.59	3.52	0.99	0.77	6.62	6.70	1.25	0.97	0.83	4.65	4.75	2.00
	8	0.95	0.83	8.19	8.50	3.63	1.00	0.79	7.04	7.12	1.08	0.96	0.85	4.63	4.73	2.08
	9	0.98	0.83	8.16	8.42	3.12	0.99	0.72	6.55	6.61	0.80	0.97	0.87	4.87	4.97	2.11
	10	0.99	0.86	8.18	8.18	0.10	1.00	0.79	6.47	6.79	4.68	0.93	0.80	4.79	4.81	0.47
Medium	1	0.99	0.88	8.15	8.24	1.09	0.96	0.79	5.94	5.96	0.39	0.97	0.78	3.85	3.93	2.04
	2	0.99	0.88	7.76	7.88	1.42	0.97	0.76	5.94	6.07	2.20	0.94	0.73	3.92	4.00	2.13
	3	0.98	0.83	7.58	7.53	0.70	0.95	0.74	5.55	5.62	1.35	0.98	0.76	3.89	3.92	0.78
	4	0.95	0.80	7.78	7.93	1.89	0.94	0.78	5.84	6.01	2.91	0.96	0.80	3.89	3.95	1.57
	5	1.00	0.87	7.92	8.09	2.12	0.99	0.83	6.08	6.12	0.60	0.95	0.71	3.85	3.93	2.08
	6	0.94	0.82	7.66	7.98	3.93	0.96	0.79	5.66	5.76	1.72	0.98	0.76	3.80	3.82	0.64
	7	0.98	0.82	7.62	7.68	0.74	0.98	0.76	5.69	5.77	1.41	0.99	0.76	3.93	3.95	0.40
	8	0.98	0.85	8.01	7.96	0.57	0.98	0.76	5.51	5.60	1.68	0.99	0.78	3.83	3.90	1.64
	9	0.99	0.86	7.80	7.96	1.93	0.98	0.72	5.86	5.97	1.94	0.97	0.85	3.84	3.86	0.64
	10	1.00	0.79	7.95	8.18	2.92	0.96	0.75	5.69	5.83	2.41	0.97	0.88	4.05	4.11	1.57
Small	1	1.00	0.93	6.24	6.35	1.74	0.97	0.76	4.53	4.60	1.43	0.97	0.82	3.31	3.38	2.12
	2	0.94	0.87	6.36	6.57	3.23	0.95	0.78	4.39	4.46	1.48	0.98	0.75	3.35	3.41	1.70
	3	0.93	0.89	6.24	6.44	3.15	0.99	0.83	4.47	4.44	0.57	0.95	0.82	3.29	3.38	2.73
	4	0.98	0.87	6.28	6.33	0.71	0.97	0.78	4.54	4.59	1.08	0.98	0.85	3.29	3.30	0.32
	5	0.97	0.87	6.25	6.32	1.15	0.96	0.80	4.55	4.64	2.10	0.98	0.82	3.30	3.32	0.66
	6	0.97	0.89	6.30	6.35	0.86	0.98	0.82	4.56	4.51	1.04	1.00	0.84	3.29	3.31	0.43
	7	0.95	0.85	6.32	6.55	3.40	0.96	0.78	4.56	4.67	2.43	0.95	0.78	3.12	3.22	3.08
	8	0.99	0.85	6.31	6.41	1.50	0.97	0.81	4.56	4.61	1.08	0.97	0.75	3.16	3.22	1.87
	9	0.98	0.92	6.28	6.49	3.18	0.96	0.81	4.47	4.49	0.43	0.97	0.75	3.18	3.25	2.01
	10	0.90	0.83	6.21	6.55	5.14	0.99	0.81	4.39	4.40	0.01	0.94	0.75	3.21	3.35	3.95

GMD_V Measuring Geometric Mean Diameter using vernier calipers
GMD_{CVS} Measuring Geometric Mean Diameter using computer vision system

was assumed to be equal to 'a' value. The percentage of error of GMD_{CV} comparing with GMD_V is about 0.03-5.14 (Table 1). We can roughly observe that the error of measuring GMD_{CV} of oranges and limes is lower than that of apples. It is due to the sample shape. According to this study the width and height of a sample was calculated from four points in a sample image, and a higher error was found either with a non-symmetrical or abnormal shape of a sample. Generally, we found that if the ratio of a/b (width) is nearly 1 and 'c' (height) at different positions of the sample is nearly the same, the percentage of error will be low. An error also occurred from the user during the marking of the points on the image. Therefore, it can be concluded that at the present this technique is a suitable method for a symmetrical object having a ratio of b to a (b/a) nearly 1 and having a normal shape.

5. Conclusions and Recommendations

- This technique is capturing a 3D image of an object in a single view with a digital camera, and then processed with a self-developed program in MatLab software. Planar metrology and the distance between two planes are applied to calculate the width and height of the object.
- It can be performed in anywhere without controlling the environment.
- It can be applied to measure the GMD of a selected fruit and vegetable (apple, orange, and lime) with 0.03-5.14 percent error.
- It is a suitable technique for measuring the GMD of a symmetrical object, for example orange and lime.

- An abnormal shape of the object and the user are causes of a higher percentage of error.
- Further research is needed to work with multiple-view object images to measure the object's volume.
- This system could result in an automatic grading machine in the future

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