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A New Framework for Measuring Volume of Axisymmetric Food Products using Computer Vision System Based on Cubic Spline Interpolation

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***Abstract*—Volume is an important factor to determine the external quality of a food product. The volume measurement of food product is not a simple process if it is performed manually. For alternative, several volume measurement methods for food products have been proposed using 2D and 3D computer vision. Disk method and frustum cone method have been applied in many 2D computer visions to approximate the volume of axisymmetric food products. These methods were less in accuracy, since it used piecewise linear function to approximate the boundary of the object. This paper aims to propose a new framework for measuring the volume of axisymmetric food product based on cubic spline interpolation. Cubic spline interpolation is employed to construct a piecewise continuous polynomial of the boundary of object from captured image. The polynomial is then integrated to approximate the volume of the object. The simulation result shows that the proposed framework produced accurate volume measurement result.**

Keywords—volume; axisymmetric; food products; computer vision; cubic spline interpolation

I. Introduction

There are several applications of volume measurement in production and processing a food product, such as for grading, sorting, and determining other physical food properties [1]. Water displacement method based on Archimedes' principle is a conventional way for measuring the volume of a food product. This method is less in accuracy, time consuming, and can damage the measured object [2]. An alternative approach for measuring the volume of food products is using computer vision system (CVS). By using CVS for volume measurement, the accuracy can be increased; the required time can be decreased, as well as food product failure can be minimized. Several CVSs have been developed for measuring the volume of food products either using 2D or 3D CVS [3].

Almost all 2D CVS for volume measurement assumed that measured object has axisymmetric shape [2, 4-7]. An object has axisymmetric shape if its cross-sections that are perpendicular to its rotation axis is circular shape, such as watermelon, egg, orange, lemon, lime, and ellipsoidal ham [8]. By using this assumption, the volume of object can be obtained by volume of solid of revolution method in Calculus [9]. In measuring the volume of food products, 2D CVS extracted the cross section of object that is parallel to rotation axis from captured image.

Sabliov, et al. [10], Du and Sun [5], and Wang and Nguang [2] have proposed 2D CVS to measure volume of axisymmetric food products using frustum cone method. They assumed that the boundary curve of object cross section that is parallel to rotation axis as piecewise continuous line. Bridge, et al. [4] and Koc [6] have proposed 2D CVS 2D CVS using disc method to measure volume of egg and watermelon, respectively. They assumed that the boundary curve of object-cross section that is parallel to rotation axis as pieces of horizontal line. The results of these approaches have a low accuracy, because a linier function has been used to approximate the boundary of object cross-section which is generally a non-linear function. Furthermore, CVSs proposed by Sabliov, et al. [10], Bridge, et al. [4], and Koc [6] were not fully automatic. They used different software for image processing and volume calculation.

In volume measurement using 3D CVS, several images of object were captured from different views [1, 11-15]. The images were then processed to reconstruct the surface of object or to generate 3D random point inside the object. In general, 3D CVS does not need any assumption about the shape of object. Therefore, it can be used to measure both axisymmetric object and irregularly shaped objects. Although, most of proposed 3D CVSs for volume measurement produced volume in high accuracy, the computational cost and computational time of the systems were very high, due to large number of images should be acquired and processed.

One of strategy to increase the accuracy of volume measurement of axisymmetric food product using volume of solid of revolution is by choosing an appropriate function to represent the boundary curve of object-cross section. Cubic spline interpolation is a numerical method for function approximation by using third order piecewise-polynomial

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from $(n+1)$ points $(x_i, f(x_i))$, $i = 0,1,2,\ldots,n$. The resulted polynomial P satisfies $P(x_i) = f(x_i)$, for all $i = 0,1,2,\ldots,n$. Moreover P has first and second order continues derivatives at all x_i, $i = 0,1,2,\ldots,n$ [16]. Therefore, the approximation of the boundary curve of object-cross section using this polynomial is better than using linier function as used in 2D CVS for volume measurement proposed by Sabliov, et al. [10], Du and Sun [5], Wang and Nguang [2], Bridge, et al. [4] and Koc [6].

This paper proposes a new framework for volume measurement of axisymmetric food products using CVS based on cubic spline interpolation. Cubic spline interpolation is used to approximate the polynomial of the boundary curve of object-cross section. The polynomial is then used to approximate volume by using integral for volume of solid of revolution. The rest of this paper is organized as follows. Section 2 describes the proposed framework. Section 3 explains the simulation of the proposed framework in measuring synthetic axisymmetric objects. Section 4 presents the result of the simulation and discussion. And section 5 provides the conclusion.

II. Proposed Framework

The proposed framework for volume measurement of axisymmetric food product consists of hardware and software frameworks. The following sub sections explain the detail of the proposed frameworks.

A. Hardware Framework

The hardware framework structure consists of a camera, two lighting sources, a black background, an object, a personal computer, and a bounding box, as shown in Fig. 1. The camera is used to capture the image of object-cross section that is parallel to rotation axis. The object is captured using the black background. This kind of background is chosen to simplify segmentation process. The object and the camera are placed inside the closed bounding box equipped with two LED lamps as lighting sources. The camera is connected to the personal computer using USB cable. The captured image is then processed in computer using software to calculate the volume of object.

B. Software Framework

The software framework is a procedural flow of steps in software used to calculate the volume of object from captured image. The steps consist of four main processes which are image acquisition, image enhancement, image segmentation, and volume approximation, as shown in Fig. 2. The details of all steps are explained as follow.

1) Image acquisition
The image of object cross-section which is parallel to rotation axis is captured using the camera and black background. Measured object is placed in the below of camera with orientation of rotation axis is parallel to horizontal axis of image coordinate. The image is captured in RGB (Red Green Blue) color space and saved in a JPEG file for further process.

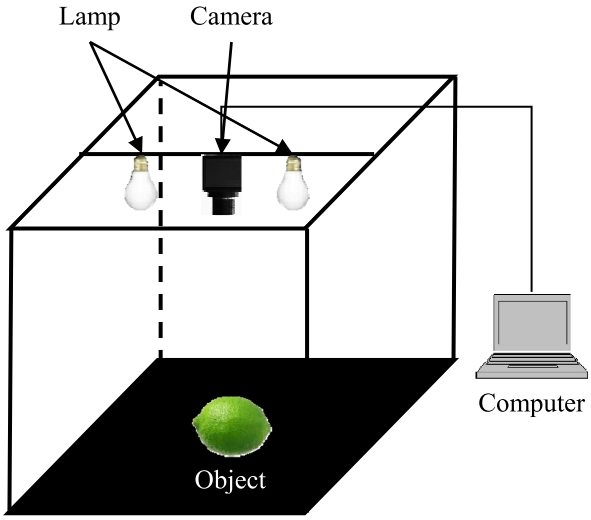

Fig. 1. Hardware framework

2) Image enhancement.
In this step, acquired image is transformed from RGB color space to a grayscale image (*Gr*). The grayscale is then filtered using Gaussian filter [17] to reduce noise resulted by camera.

3) Segmentation.
This step is used to separate object from its background. The result of this step is a binary image. Thresholding technique [17] is used to perform segmentation. The threshold value T is determined automatically using Otsu method [18]. Morphological opening and closing operations [17] are the used to remove misclassified pixels.

4) Volume approximation
This step is performed to approximate the volume of food product from the binary image. The following steps are used to obtain the volume of object:

- Determine the region of interest (ROI) on the binary image. The ROI is defined as a minimum axis alignment bounding rectangle containing the object.
- Crop the binary image according to the ROI.
- Determine x and y axis of 2D real world coordinate system.
- Determine the scale factor to transform length in image coordinate system to 2D real world coordinate system.
- Determine the coordinate of $(n+1)$ points on the upper half of the boundary object, (x_i, y_i), $i = 0,1,2,\ldots,n$ in 2D real world coordinate system. The amount of n will be determined during experiment.

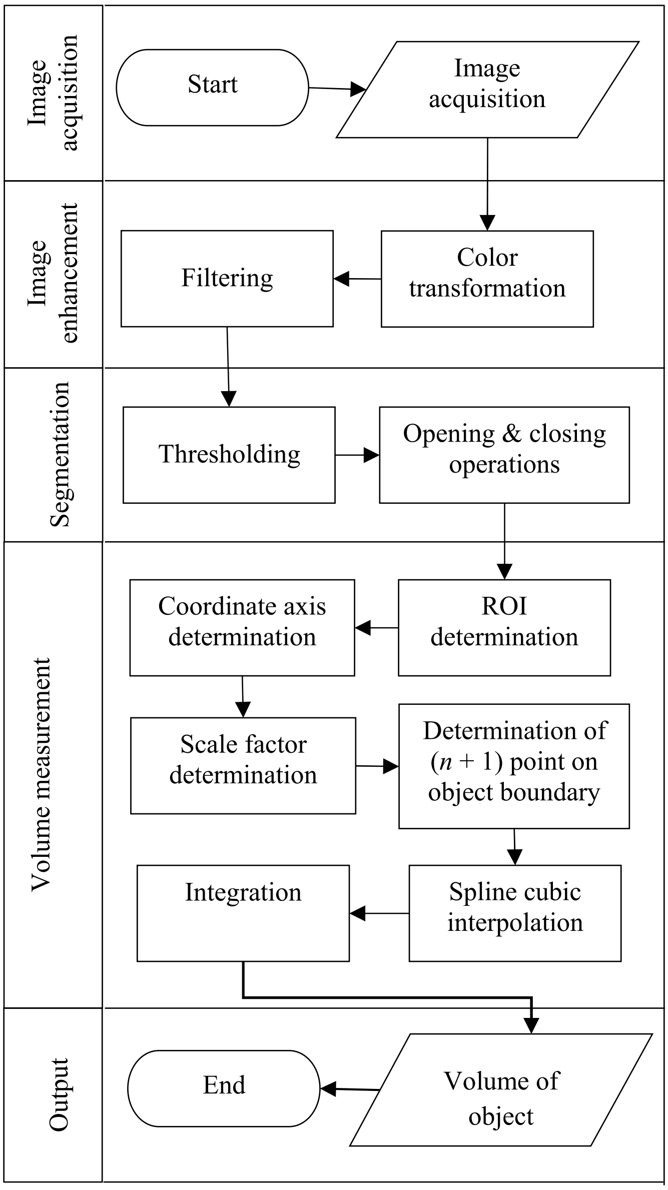

Fig. 2. Software framework

- Construct piecewise cubic polynomial S using cubic spline interpolation from (x_i, y_i^2), $i = 0,1,2,\ldots,n$, as in (1).

$$S(x) = a_j + b_j(x - x_j) + c_j(x - x_j)^2 + d_j(x - x_j)^3, \quad x_j \le x \le x_{j+1}, j = 0,2,\ldots,n-1 \tag{1}$$

- Approximate the volume of object using integral for volume of solid of revolution, as in (2) and (3).

$$V = \int_{x_0}^{x_n} \pi S(x)dx \tag{2}$$

$$V = \pi\sum_{j=0}^{n-1} a_j(x_{j+1} - x_j) + \frac{b_j}{2}(x_{j+1} - x_j)^2 + \frac{c_j}{3}(x_{j+1} - x_j)^3 + \frac{d_j}{4}(x_{j+1} - x_j)^4 \tag{3}$$

III. SIMULATION

An experiment is currently performed in laboratory to validate the proposed volume measurement framework. A number of axisymmetric food products, including eggs, oranges, and lemons are used in the experiment. For initial study, a simulation of volume measurement using the proposed framework has been done using six synthetic axisymmetric objects, as shown in Fig. 3.

The synthetic object was obtained by revolving a region bounded by one or two curve(s) and the x axis about the x axis. The synthetic binary image of each object cross-section which is parallel to rotation axis was also generated based on the revolved region. The binary image was then used to approximate the volume of object using the proposed framework. The detail of the objects is as follow.

- Object 1 is a solid obtained by revolving a region bounded by curve $y = x\sin(x)/4 + 0.3$, $0 \le x \le 3$, and $y = 0$ about the x axis. The object and its binary image are shown in Fig. 3 a and Fig. 3 b, respectively.
- Object 2 is a solid obtained by revolving a region bounded by curve $y = 2 - \cos(x)$, $0 \le x \le 7$, and $y = 0$ about the x axis. The object and its binary image are shown in Fig. 3 c and Fig. 3 d, respectively.
- Object 3 is a solid obtained by revolving a region bounded by curve $y = ((x-2)^2/2 - 0.7)^2 - 2$, $0 \le x \le 4$, and $y = 0$ about the x axis. The object and its binary image are shown in Fig. 3 e and Fig. 3 f, respectively.
- Object 4 is a solid obtained by revolving a region bounded by curve $y = (x/2)\sqrt{1 + \sin(x/3)^2}$, $0 \le x \le 6.5$, and $y = 0$ about the x axis. The object and its binary image are shown in Fig. 3 g and Fig. 3 h, respectively.
- Object 5 is a solid obtained by revolving a region bounded by curve $y = \sqrt{4 - (x-2)^2}$, $0 \le x \le 4$, and $y = 0$ about the x axis. The object and its binary image are shown in Fig. 3 i and Fig. 3 j, respectively.
- Object 6 is a solid obtained by revolving a region bounded by curve $y = 0.7\sqrt{4 - (x/0.9 - 1)^2}$, $0 \le x \le 0.9$, $y = 0.7\sqrt{4 - (x/1.3 - 0.9/1.3)^2}$, $0.9 \le x \le 2.2$, and $y = 0$ about the x axis. The object and its binary image are shown in Fig. 3 k and Fig. 3 l, respectively.

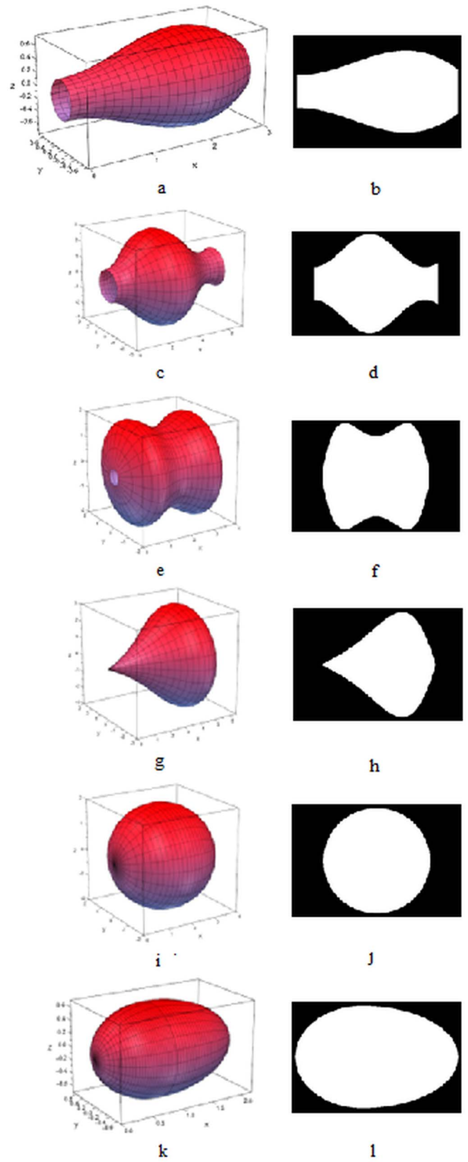

Fig. 3. The synthetic axisymmetric objects and its binary images

IV. Results and Discussion

The volume measurement accuracy of the proposed framework was assessed using absolute relative error (ARE), as in (4).

$$\text{ARE} = \frac{|V_E - V_C|}{V_E} \times 100\% \quad (4)$$

V_E is the exact volume of the object. It is calculated using integral for volume of solid of revolution. V_C is the volume of the object measured using CVS.

The volume measurement results using the proposed framework, the exact volume, and the absolute relative error are tabulated in Table I. For comparison, the volume of the synthetic object was also measured using disc method [6] and frustum cone method [2], the results are also shown in Table I. From Table I, it can be observed that the volume measurement result using the proposed framework has smaller ARE compared to the volume measurement result using disk method and frustum cone method for all objects used in the simulation.

The proposed framework produced the minimum ARE of 0.016% in measuring Object 2 and produced the maximum ARE of 1.620% in measuring Object 5. Disk method and frustum cone method got minimum ARE of 0.095% and 0.158%, respectively, in measuring Object 1. The maximum ARE for disk method and frustum cone method were 2.081% in measuring Object 6. In average, ARE for the proposed framework, disk method, and frustum cone method were 0.625%, 0.924%, and 0.953%, respectively. This result shows that the volume measurement result using the proposed framework is more accurate than the volume measurement results using disk method and frustum cone method.

TABLE I. Simulation Result

Obj.	**V_E (cc)**	**The proposed framework**		**Disc method**		**Frustum cone method**	
		V_A (cc)	***ARE (%)***	***V_A (cc)***	***ARE (%)***	***V_A (cc)***	***ARE (%)***
1	3.173	3.172	0.032	3.170	0.095	3.168	0.158
2	91.482	91.497	0.016	91.138	0.376	91.054	0.468
3	35.545	35.575	0.084	35.481	0.180	35.474	0.200
4	76.576	77.089	0.670	77.193	0.806	77.190	0.802
5	33.51	32.967	1.620	32.838	2.005	32.836	2.011
6	2.258	2.228	1.329	2.211	2.081	2.211	2.081
Average			**0.625**		**0.924**		**0.953**

V. Conclusion

A new framework for measuring the volume of axisymmetric food products using computer vision system based on cubic spline interpolation has been proposed. To measure the volume, the image of object cross-section which is parallel to rotation axis is captured using a camera. The captured image is then processed to produce a binary image. A piecewise continuous polynomial is constructed to approximate the boundary of the cross-section of measured object from the binary image using cubic spline interpolation. The polynomial is then integrated using integral for the volume of solid of revolution to produce the volume of object. As initial study, a simulation has been conducted to validate the proposed framework, using six synthetic axisymmetric objects. The simulation result shows that the proposed framework produced accurate volume measurement result with average absolute relative error of 0.625%. In addition, the proposed framework produced smaller absolute relative error than disk method and frustum cone method.

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