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# Volumetric prediction of symmetrical-shaped fruits by computer vision

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## ABSTRACT

Computer vision in the industrial sector has the highest level of need because the work is done automatically and can speed up and save time for work productivity. Not always, work will be done manually by human workers who sometimes have obstacles in the process of taking place. The high cost causes the need for technology to simplify work so it does not materialize. A simple imaging system with computer vision is proposed in this study. Measurement of volume estimates from several samples was carried out to see the efficiency of computer vision imaging work by comparing the measurement results manually and water displacement method. Computer vision imaging is built using a CMOS camera, line laser, Raspberry Pi, Python programming language, and OpenCV. Imaging results show that computer vision has the ability to read the sample volume estimate more effectively against objects that have a symmetrical shape. The smallest error percentage of measurement of volume estimation by computer vision against manual method and the water displacement was 7.44% and 7.18% for sunkist oranges and 10.88% and 13.67% for symmetrical watermelon, respectively.

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## 1. INTRODUCTION

Global technological developments are currently entering the industrial era 4.0. This is a work system that combines the digital world and the timeliness of completing work. This industry prioritizes automation in various fields [1-3]. The development and use of the latest technology and automation in agriculture towards industry 4.0 is increasingly being carried out along with developments in computers, sensors and detectors [4], as well as signal and image processing methods such as early detection of plant diseases [5], harvesting fruit using robots [6], sorting and quality determination as well as fruit storage [7]. However, the innovation that needs to be developed in the agricultural sector is an automation system for sorting the products using the imaging method. Automation systems have the ability to sort products more efficiently in terms of quantity and time, compared to conventional systems that use human labor and are subjective [8-10]. This is very profitable and plays an important role for large-scale agricultural industry.

Computer vision (CV) is an imaging method that uses a computer and a camera as a device system. This method has several advantages, including that it is non-destructive, fast, more accurate for repetitive work, and is quantitative in nature, so that the quality of the product can be determined [11]. In this study, an estimation of the volume of the fruits was carried out using a 3D imaging model to determine the depth or height of the object in order to obtain volume. The imaging model is able to evaluate or inspect the external and internal conditions of an object that has a symmetrical or asymmetrical shape [12, 13]. This makes 3D imaging in estimating volume a quality and efficient attribute that can be used in post-harvest sorting systems in agriculture [14]. Volume estimation requires an approach in the form of algorithms for various object shapes, so that the 3D imaging model with the CV method is applied with a spherical and ellipsoid volume approach [15], as has been done in previous studies with melons [16], watermelon [12], kiwi [17], and tangerine [18], all of which have symmetrical and asymmetrical shapes.

An automatic volume estimation system for symmetric and asymmetrical sample objects is applied in this study with an imaging method built using a CMOS camera, line laser, and Raspberry Pi. Python and OpenCV programming languages that have been developed by Prayitno et al. (2020) used in this research to estimate the volume of an object [19]. The results of volume estimation with CV imaging will be compared with the results using water displacement method and manual calculations to determine the accuracy of the estimation results.

## 2. MATERIALS AND METHODS

This section describes the collection of several materials or objects used as research samples and methods of determining sample volume. This study used three volume measurement methods, namely manual imaging, water comparison (Archimedes), and computer vision imaging. The results of manual volume estimation and Archimedes will be used as a comparison against computer vision to see the effective performance of the image.

### 2.1. Objective Samples

The sample objects used in this study consisted of fruit in the form of lemon, guava, papaya, eight orange sunkist each and six watermelons. An overview of the samples can be seen in Figure 1. All samples have various masses and sizes.

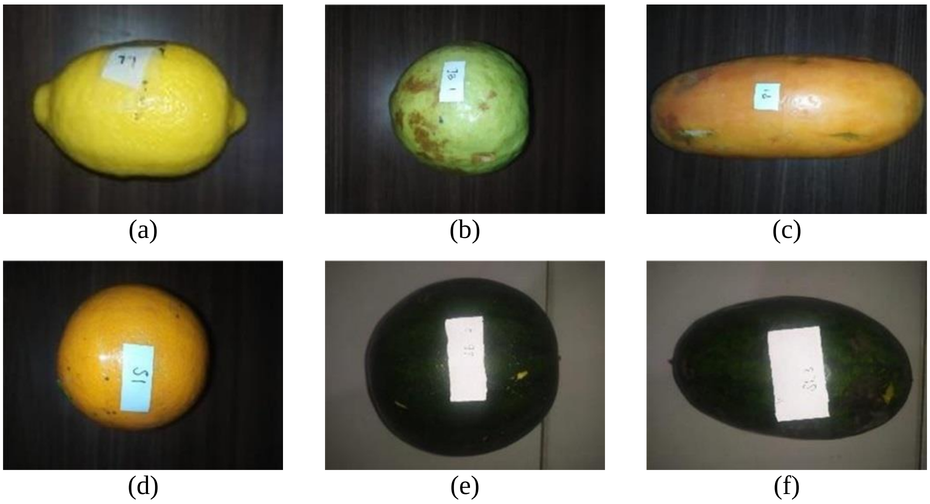


Figure 1. Fruit sample in this work: (a) lemon; (b) guava; (c) papaya; (d) Sunkist oranges; (e) spherical watermelon; and (f) elliptical watermelon.

Table 1. The mass group of objective samples.

| Lemon | | Guava | | Papaya | | Sunkist Oranges | | Spherical Watermelon | | Elliptical Watermelon | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Label | Mass (gr) | Label | Mass (gr) | Label | Mass (gr) | Label | Mass (gr) | Label | Mass (gr) | Label | Mass (gr) |
| L1 | 139 | G1 | 320 | P1 | 397 | S1 | 230 | SW1 | 5017 | AW1 | 2901 |
| L2 | 141 | G2 | 340 | P2 | 656 | S2 | 233 | SW2 | 4772 | AW2 | 2989 |
| L3 | 141 | G3 | 359 | P3 | 668 | S3 | 237 | SW3 | 4512 | AW3 | 3176 |
| L4 | 144 | G4 | 359 | P4 | 698 | S4 | 238 | - | - | - | - |
| L5 | 145 | G5 | 370 | P5 | 715 | S5 | 245 | - | - | - | - |
| L6 | 153 | G6 | 371 | P6 | 726 | S6 | 247 | - | - | - | - |
| L7 | 156 | G7 | 371 | P7 | 959 | S7 | 250 | - | - | - | - |
| L8 | 160 | G8 | 388 | P8 | 1050 | S8 | 252 | - | - | - | - |

The sample is first measured by mass manually with a digital scale which has a high degree of accuracy. Then, the samples are arranged according to their mass values from smallest to largest. The results of mass measurement of all samples can be seen in Table 1. Based on sample grouping, watermelon fruit is divided into two types in terms of shape. The sample which has an regular spherical shape here is called a spherical watermelon, while an oval shape is called elliptical watermelon [20].

### 2.2. Volumetric Estimation Methods

Measurement of the volume of all samples in this study using three methods, namely manual calculation, water displacement method, and the CV. The reason the three methods are applied is to compare all the volume estimation results for each sample, especially the method with the CV imaging which needs attention to its accuracy.

#### 2.2.1. Manual Calculation

This method takes volume measurements manually, where the transverse and longitudinal lengths of the fruits are measured using a ruler. The sample volume is then calculated based on the parameters of length, width and height [21]. The data obtained is then stored for later use as a comparison.

#### 2.2.2. Water Displacement Method

The water displacement method is one of the conventional methods used to measure the volume of an object, both regular and irregular. This method is based on the principle of calculating the relationship between volume and mass by the water displacement [22]. The sample will be completely immersed in water, which causes the water level to change from its original position. Thus, the measurement of the sample volume can be calculated based on the parameters of the length, width and height of the resulting water level.

#### 2.2.3. Computer Vision

The 3D CV imaging system used consists of a box that is useful for recording sample images. The CMOS camera is used as an image recorder connected to the Raspberry Pi microcomputer via the camera sensor interface connection. On the Raspberry Pi, code is developed to capture images from the camera and store images using the Pi camera library. The line laser is used to form the profile of the sample. When the laser beam hits the sample surface, there will be a fracture in the major and minor axes of the sample. A Python-based computer program was developed to calculate the distance between the faults on the two axes. Furthermore, height measurements are carried out for objects that are not symmetrical, by tilting the object and measuring the fracture distance using a program that has developed a system for estimating volume and mass of symmetrical agricultural products that automatically uses the imaging method built using a CMOS camera, line laser, and Raspberry Pi [19]. Illustration of CV imaging system design can be seen in Figure 2.

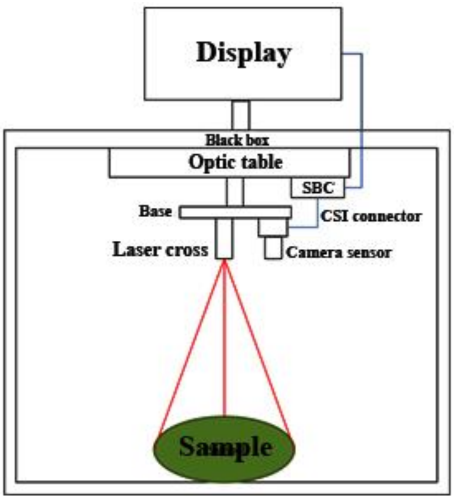


Figure 2. Schematic of the CV imaging system.

The CV system is built using a camera and laser which has been arranged according to the laser triangulation method. The python programming language used is useful for building automated systems, as well as importing data on the numerical formulation needed to determine the volume of a symmetrical fruit sample. Image processing with CV will show the pixels of the line laser and the lengths of the major and minor axes of the symmetrical fruit sample. The volume will be displayed in real time on the computer screen for each sample in front of the camera.

### 2.3. Mathematical Formula

The volume estimation program consists of several steps, including determining the distance between the object and the laser, determining the length and height of the object. The acquired minor, major and height parameters are then used as parameters for volume estimation using the following equation [23].

$$V_{symmetrics} = \frac{4}{3}\pi abc \quad (1)$$

$$V_{elliptics} = \pi L D_1 D_2 \quad (2)$$

where, $V$ is the volume, the parameters $a$, $b$, and $c$ are the length, width and height of the object, respectively. Then $L$ is the length of the sample, and $D_1$ and $D_2$ are the inner and outer heights, respectively.

## 3. RESULTS AND DISCUSSIONS

The measurement of volume estimates for several fruit samples using the three proposed methods has been carried out. Several volume measurements using the three methods resulted in significant differences in certain samples. Samples that have various sizes, both regular and regular, can affect the measurement of volume estimates. What's more, the imaging system with CV is still not perfect. The manual method and water displacement are used as a comparison for the 3D CV imaging system. Based on the measurement results, most of the manual methods have almost the same accuracy as the water displacement. Because the differences are quite a bit different for CV imaging systems with manual methods and water displacement, however, in some samples there are measurements with these three methods having the same volume estimation.

Based on the graph in Figure 3 (a) for the lemon, the measurement results of the estimated volume that are almost close together are found in the L6 sample, where the volume obtained for CV is 141.3 cm$^3$, and it is comparable to the manual calculation and water displacement are 154.99 cm$^3$ and 158.32 cm$^3$, respectively. The difference in volume estimation for manual with the water displacement is approximately 0.004 cm$^3$. Meanwhile, C has a difference of 0.015 cm or the percentage of errors obtained is an average of 9.79%.

For the guava fruit in Figure 3 (b), sample G8 has almost the same volume estimate for the three methods. The volume measurements obtained for manual calculation, the water displacement, and CV were 393.42 cm$^3$, 437.35 cm$^3$, and 413.93 cm$^3$, respectively. The difference obtained by CV with the manual method and the water displacement is 0.02 cm or an average error percentage of 5.28%.

Furthermore, samples P6 and P7 for papaya fruit each have the same volume estimation for each measurement result manually and the water displacement which can be seen in Figure 3 (c). Sample P6, has a difference of 0.003 cm with the acquisition of an estimated volume of 570.18 cm3 for the CV method, while the P7 sample has a difference of 0.02 cm with a volume size of 945 cm$^3$. The average percentage of CV errors from samples P6 and P7 against manual and the water displacement methods were 2.8% and 3.88%, respectively.

The samples that show perfect estimation results or equal to the three methods are found in the S8 sample or can be seen in Figure 3 (d). The S8 sample has very little difference to the manual calculation and water displacement method of 0.0009 cm$^3$. The results for the volume estimation for manual calculation, the water displacement, and CV are 239.09 cm$^3$, 241.47 cm$^3$, and 238.78 cm$^3$, respectively. The percentage of errors obtained for the CV method against manual and the water displacement methods is an average of 0.62%. The difference in volume measurement measurements obtained by CV from manual calculation and the water displacement results, is due to the incorrect placement and timing of the measurements, which causes errors in reading each pixel point and major and minor axes by laser lines, although slightly [24]. Not only that, complicated or irregular fruit samples cause laser image readings to be less precise and laser readings that are only on one side of the sample [25].

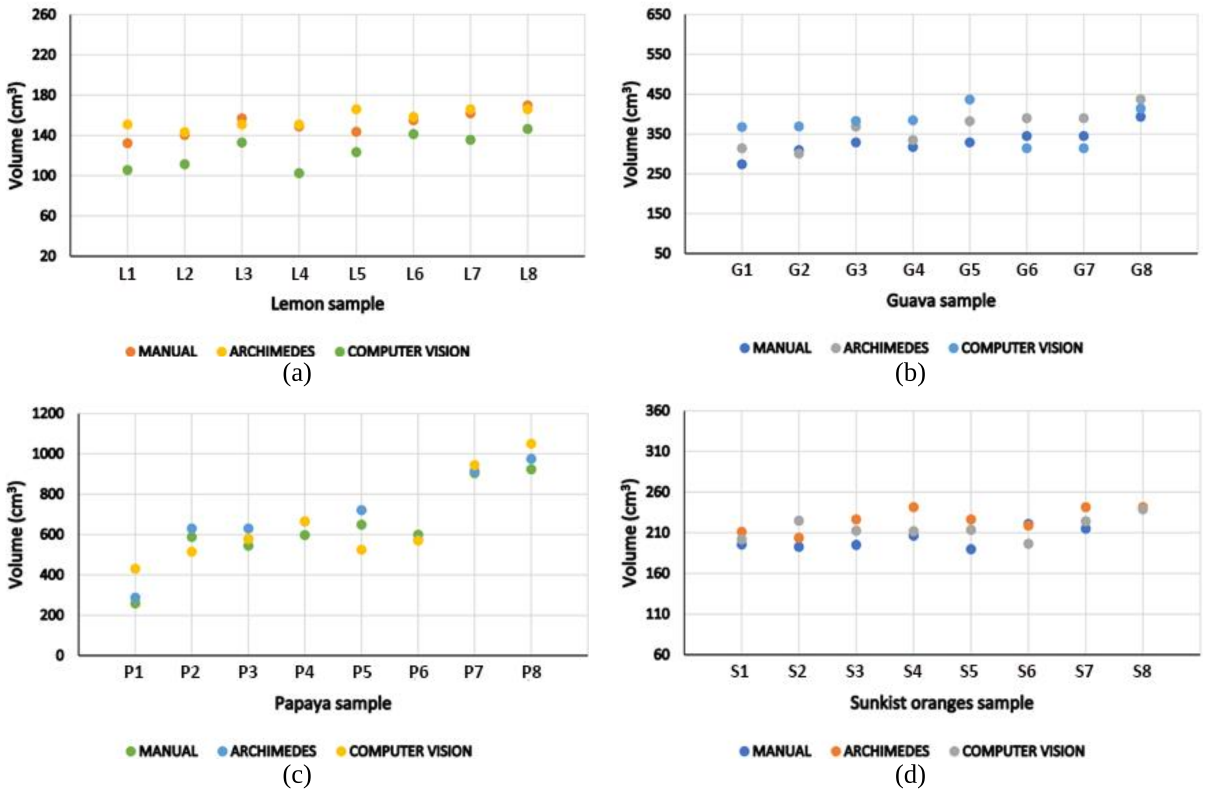


Figure 3. Comparison of volume estimation with all methods on samples: (a) lemon; (b) guava; (c) papaya; and (d) Sunkist oranges.

Table 2. The percentage error in estimating the volume of each sample object.

| Sample | Label | Error percentage with CV method (%) | | Sample | Label | Error percentage with CV method (%) | |
|---|---|---|---|---|---|---|---|
| | | Manual | The water displacement | | | Manual | The water displacement |
| Lemon | L1 | 20.11 | 29.94 | Papaya | P1 | 66.58 | 50.17 |
| | L2 | 20.79 | 22.38 | | P2 | 12.46 | 18.28 |
| | L3 | 15.28 | 11.91 | | P3 | 6.07 | 8.26 |
| | L4 | 31.15 | 32.05 | | P4 | 11.50 | 0.26 |
| | L5 | 13.99 | 25.59 | | P5 | 19.28 | 27.29 |
| | L6 | 8.83 | 10.75 | | P6 | 4.95 | 0.66 |
| | L7 | 16.26 | 18.25 | | P7 | 4.44 | 3.32 |
| | L8 | 13.80 | 11.80 | | P8 | 13.71 | 7.67 |
| Guava | G1 | 34.00 | 17.00 | Sunkist Oranges | S1 | 3.36 | 4.38 |
| | G2 | 19.29 | 22.94 | | S2 | 16.68 | 10.41 |
| | G3 | 16.31 | 3.74 | | S3 | 8.88 | 6.20 |
| | G4 | 21.07 | 14.80 | | S4 | 2.68 | 12.20 |
| | G5 | 32.72 | 14.26 | | S5 | 12.47 | 5.72 |
| | G6 | 8.84 | 19.32 | | S6 | 11.06 | 10.25 |
| | G7 | 8.84 | 19.32 | | S7 | 4.26 | 7.15 |
| | G8 | 5.21 | 5.35 | | S8 | 0.13 | 1.11 |

The imaging system with CV is sufficient to provide positive results on its work efficiency as an image tool to estimate the volume of fruit samples. In Table 2, there is a percentage of errors obtained by CV on manual and the water displacement methods for all samples. When viewed based on the results obtained, the lemon sample for CV has an average overall error percentage of 17.53% and 20.33% for manual calculation and water displacement methods, where the smallest error percentage is in the L6 sample. The mean percentage of CV errors for the other samples was 18.28% and 14.59% for guava fruit and 17.37% and 14.49% for papaya fruit. In addition, for the CV Sunkist oranges fruit sample had the smallest error percentage, with an average of 7.44% and 7.18% for manual and water displacement methods, respectively. This proves that the 3D imaging system with CV works very effectively on objects with symmetrical shapes. When viewed, Sunkist oranges have a more symmetrical size compared to other fruit samples, so that the laser reading of the sample is less error-free and accurate.

Table 3. Comparison of volume estimates and relative error percentages for watermelon samples.

| Sample | Label | Volume ($cm^3$) | | | Error percentage with CV (%) | |
|---|---|---|---|---|---|---|
| | | Manual | The water displacement | CV | Manual | The water displacement |
| Symmetrical watermelon | SW1 | 8892.00 | 7850.03 | 8630.20 | 3,03 | 9,94 |
| | SW2 | 6290.00 | 7371.41 | 6199.60 | 1,46 | 15,90 |
| | SW3 | 5818.25 | 7029.54 | 8096.36 | 28,14 | 15,18 |
| Elliptical watermelon | AW1 | 3096.00 | 5276.82 | 3108.79 | 0,41 | 41,09 |
| | AW2 | 3696.00 | 5562.11 | 2777.73 | 24,85 | 50,06 |
| | AW3 | 4508.00 | 5783.26 | 4487.12 | 0,46 | 22,41 |

Table 3 shows the results of the volume estimation measurements for watermelon fruit samples. Watermelon is classified based on shape, namely symmetrical and non-symmetrical. Based on the results obtained, the symmetrical watermelon sample has a relatively smaller average error than asymmetrical. The mean percentages of CV error for manual calculation and water displacement methods were 10.88% and 13.67% for symmetrical watermelon and 8.57% and 37.85% for asymmetric watermelon, respectively. This clarifies again based on the previous discussion that imaging systems with CV have greater work efficiency on symmetrical objects compared to irregular shapes.

## 4. CONCLUSION

Volume estimation based on the 3D imaging system with the CV method has a more effective object reading of a symmetrical sample. Lemon, guava, papaya, and watermelon which have an asymmetrical shape have a greater percentage of volume measurement error than Sunkist orange and watermelon which have a symmetrical shape, with the results obtained for 7.44% and 7.18% for the oranges sunkist and 10.88% and 13.67 % for symmetrical watermelon, respectively to manual calculation and water displacement method.

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