

# A methodology to measure the volume of spheroid and oblong solid bodies based on artificial vision technique

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A methodology for assessing the volume of spheroid and oblong solid bodies is presented. Samples were mounted on a revolving platform that was driven by a computer-controlled stepping motor. Four hundred views (photographs) of each sample were acquired as they were uniformly rotated in the azimuth direction. The image processing was based on the artificial vision technique called *segmentation*. Using the information of the instantaneous radius and the small angle of rotation in each step, the numerical integration of the volume was performed. Images were captured using a CCD camera and the entire system was controlled by a routine developed in LabVIEW<sup>TM</sup> 6.1. Two sets of geometrical bodies (polystyrene cylinders and spheres) and three kinds of biological samples were measured. For the sake of comparison, each body was also measured by means of both a micrometric caliper and the displaced volume of water inside a vessel. The ANOVA correlation parameters between the proposed methodology and the hydrostatic procedure were found to be:  $r = 0.9924$  and  $p = 0.0001$ , with  $\alpha = 0.05$ . The coincidence between the results obtained with artificial vision and the hydrostatic technique was greater than 98% for spheres and cylinders. On the other hand, it was only up to 95% for the samples with non-regular shaped bodies (chicken hearts, kidneys and carrots). The purpose of the paper is to discuss in detail a simple technique which could be of interest to students of science and engineering.

**Keywords:** Artificial vision; volume assessment; image processing.

Una metodología para evaluar el volumen de cuerpos sólidos esféricos y oblongos es presentada. Las muestras fueron montadas en una plataforma giratoria, manejada por un motor de paso controlado por una computadora. 400 vistas (fotografías) de cada muestra fueron adquiridas a medida que ellas fueron uniformemente rotadas en la dirección azimutal. El procesamiento de imagen estuvo basado en la técnica de visión artificial llamada *segmentación*. Usando la información del radio instantáneo y el pequeño ángulo de rotación en cada etapa, la integración numérica del volumen fue desarrollada. Las imágenes fueron capturadas usando una cámara CCD y el sistema completo fue controlado por una rutina desarrollada en LabVIEW<sup>TM</sup> 6.1. Dos conjuntos de cuerpos geométricos (cilindros y esferas de poliestireno) y tres clases de muestras biológicas fueron medidos. Para fines de comparación, cada cuerpo fue también medido por medio de un pie de rey micrométrico, así como el volumen de agua desplazada dentro de un envase. Los siguientes parámetros de correlación ANOVA entre la metodología propuesta y el procedimiento hidrostático fueron encontrados:  $r = 0.9924$  y  $p = 0.0001$ , con  $\alpha = 0.05$ . La coincidencia entre los resultados obtenidos con visión artificial y la técnica hidrostática fue mayor a 98% para esferas y cilindros. Por otro lado, fue de alrededor de 95% para las muestras con cuerpos de forma irregular (corazones de pollo, riñones y zanahorias). El propósito del artículo es discutir con detalle una técnica simple la cual pudiera ser de interés para estudiantes de ciencias e ingeniería.

**Descriptores:** Visión artificial; evaluación de volumen; procesamiento de imagen.

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## 1. Introduction

The assessment of body volumes is a routine procedure of interest in a variety of applications. In particular, the determination of the volume of some organs or parts of the body by using images obtained with different techniques such as magnetic resonance imaging [1], X-ray absorptiometry [2], computed tomography [3,4], etc, is a common practice in medicine. Also, a procedure to measure solid body volumes directly, in several fields of science, is the hydrostatic weighing (HW) technique [5], currently considered a *gold standard*. On the other hand, the artificial vision (AV) technique is an important research field in the recognizing of geometrical patterns and shapes to reconstruct volumes [6-8]. In

this paper, a methodology to measure volumes of solid bodies with spheroid and oblong shapes is implemented. It is based on the automatic acquisition of images by means of AV techniques, using a personal computer (PC), a charge coupled device camera (CCDc) and a LabView<sup>TM</sup> 6.1 (LV) programming environment.

## 2. Material and methods

### 2.1. Mathematical algorithm

An algorithm for numerical integration was implemented in a program written on LV platform. Also, a system of AV was

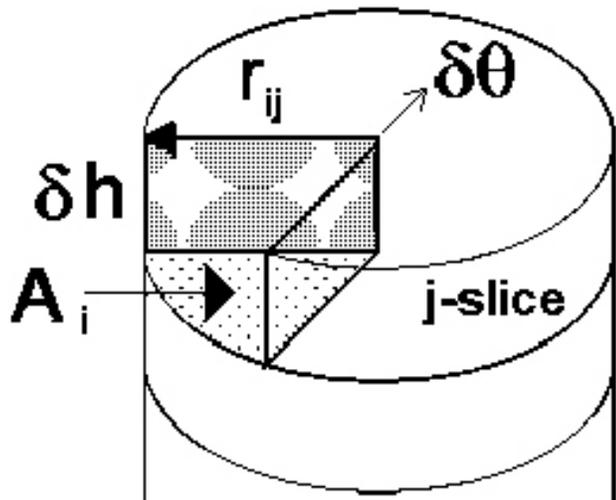


FIGURE 1. Representation of the *i*th-piece of the *j*th-slice of the object, as was chosen by the algorithm described in the text.

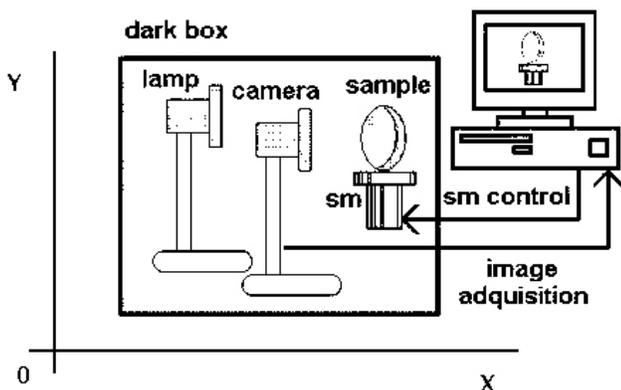


FIGURE 2. A schematic diagram of the experimental setup.

performed to work controlled by a personal computer using the same software, the LV. The sample was rotated, with a stepping motor (SM), in a vertical direction (the Y direction, see Fig. 2) while a CCDc captured the image and analyzed the profile of the body. Then, the total volume was computed by using the algorithm described next, which works as follows: The body was horizontally divided into *m* slices with thickness  $\delta h$ . Each slice was divided into *n* thin pieces ( $n = 400$ ), starting from the rotation axis, by using radial lines with length *r*. Note that each piece of an arbitrary slice, that we shall call volume element  $\delta V_{ij}$ , subtended an inner angle of  $\delta\theta = 2\pi/n$ . The same number of photographs, *n*, was taken when the body rotated *n* steps. The curvature along  $\delta\theta$  in each  $\delta V_{ij}$  is considered constant, whenever  $2\pi/n < 1^\circ$ . Figure 1 shows a representation of an arbitrary  $\delta V_{ij}$  corresponding to the *i*th-piece of the *j*th-slice of the body, as chosen by the integration algorithm. The bottom area  $A_{ij}$  is that swept by  $\delta\theta$ , and is given by

$$\delta A_{ij} = \frac{1}{2} r_{ij}^2 \delta\theta, \tag{1}$$

TABLE I. The comparison exhibited between the AV technique and the direct measurement by a caliper illustrates the accuracy of the methodology presented in this work. The values were obtained from a set of cylindrical bodies, and each one corresponds to the average of ten measurements.

| AV technique measurement (cm <sup>3</sup> ) | Direct measurement, by using a caliper (cm <sup>3</sup> ) | Differences (cm <sup>3</sup> ) | Uncertainty (%) |
|---|---|--------------------------------|-----------------|
| 25.45                                       | 25.06   | 0.39                           | 1.56            |
| 47.87                                       | 47.47   | 0.40                           | 0.84            |
| 79.65                                       | 79.13   | 0.52                           | 0.66            |
| 137.21                                      | 137.33  | 0.12                           | 0.09            |
| 178.83                                      | 178.94  | 0.11                           | 0.06            |
| 277.15                                      | 276.97  | 0.18                           | 0.06            |

TABLE II. Comparison of volume measurements for non-regular bodies (carrots) obtained by both AV and HW techniques, respectively.

| AV technique measurement (cm <sup>3</sup> ) | HW technique measurement (cm <sup>3</sup> ) | Differences (cm <sup>3</sup> ) | Uncertainty (%) |
|---|---|--------------------------------|-----------------|
| 18.88                                       | 20.31                                       | 1.43                           | 7.04            |
| 22.60                                       | 22.79                                       | 0.19                           | 0.83            |
| 23.74                                       | 23.06                                       | 0.68                           | 2.95            |
| 24.62                                       | 25.10                                       | 0.48                           | 1.91            |
| 31.75                                       | 31.45                                       | 0.30                           | 0.95            |
| 31.92                                       | 31.98                                       | 0.04                           | 0.19            |

where it is important to note that  $r_{ij}$  is the actual geometrical information obtained by the CCDc. Also,  $\delta\theta$  is obtained from the parameters of the software controlling the SM. Hence, the volume of the *j*th-slice is:

$$\delta V_j = \delta h \sum_{i=1}^n \delta A_{ij}, \tag{2}$$

and so, the volume of the body, which is obtained by integrating all the  $\delta V_{ij}$  along the *m* slices, is given as:

$$V = \sum_{j=1}^m \delta V_j = \delta h \frac{\pi}{n} \sum_{j=1}^m \sum_{i=1}^n r_{ij}^2. \tag{3}$$

### 2.2. Instrumentation

The experimental setup was composed of a commercial 8 bit, monochromatic camera (model RS-170), and an 8 bit image acquisition card. A CCDc of 12.7 mm was used. A stepping motor controlled by a PC through the parallel port drove the revolving platform used to rotate the sample. A 20 W fluorescent bulb was used to illuminate the sample and all the hardware was inside a black box. Using that hardware, it

was possible to acquire 400 consecutive images at equidistant angles, and the volume of the body was computed. The image acquisition, the numerical procedure and the mechanical control of the experiment were implemented in a routine developed in LV environment. In Fig. 2 a schematic diagram of the experimental setup is shown.

### 2.3. Measurement procedure

Two polystyrene geometrical types of bodies and three kinds of biological samples were used in this study. Volume assessments were performed by using AV on polystyrene cylinders and spheres and, also, on carrots and chicken organs (hearts and kidneys). Just for comparison, volume measurements were also performed by using the HW technique.

In order to validate both the experimental arrangement and the mathematical algorithm implemented, samples of six different sizes were measured for each type of object. In particular, the volumes of six steel spheres and six plastic cylinders were measured with calipers of 10  $\mu\text{m}$  of accuracy, for calibration and traceability. In using the AV technique, the samples were in a field of vision of 10 cm, and they were held on top of a revolving disc, which changed its orientation with respect to the camera lens 400 steps in 30 seconds. The CCDc was 20 cm away from the center of the disc and all the samples were placed at this point. One picture was taken for each position, and each image underwent an image segmentation process, and then the numerical algorithm implemented was applied for calculation of the volume. In order to find an average volume, each object was measured ten times with both AV technique and a caliper (direct measurement), respectively. Table I shows a comparison of the values obtained for six plastic cylinders with both procedures. The corresponding differences and uncertainties are also shown.

On the other hand, in the case of non-regular bodies such as carrots and biological organs, a validation of the measurements cannot be performed with a direct measurement by using a pair of calipers. In this case, the HW technique was employed for comparison. Table II shows the volumes of six different carrots and their comparison with the results obtained with the HW technique.

### 2.4. Analysis of experimental uncertainties

In order to evaluate the AV methodology proposed, for bodies of regular shapes, a set of samples, cylinders and spheres, were directly measured with a pair of calipers, and the global uncertainty of the measurement was related to it. The best accuracy was reached for the cylinders with an uncertainty less than 1.5%, in most of the cases; this can be inferred from Table I.

On the other hand, the volume measurements with the HW technique were taken by submerging the samples in water, inside a graduated vessel. The rising of the level of water is essential in determining the volume of the sample, and its error is the main contribution to the uncertainties in this tech-

nique. The uncertainty in the measurement of a finite element of volume, derived from Eq. (2):  $V = r^2\theta h/2$ , depends on the uncertainty in  $r$  ( $\Delta r$ ),  $\theta$  ( $\Delta\theta$ ) and  $h$  ( $\Delta h$ ), respectively. In fact, the relative uncertainty is

$$\frac{\Delta V}{V} = \frac{\Delta h}{h} + \frac{\Delta\theta}{\theta} + 2\frac{\Delta r}{r}, \quad (4)$$

The measurements of  $r$  and  $h$  are affected by slight variations in the light source intensity and the CCDc resolution.  $\Delta r/r$  was established at around 1% – or less – and the same holds for  $\Delta h/h$ . These variations lead to fluctuations in the darkness of the pixels located at the sample contour, affect the binarizing of the image and then the volume assessment.  $\Delta\theta/\theta$  had the high precision of the SM mechanism, and its contribution to Eq. (4) is negligible. With these considerations,  $\Delta V/V$  is bounded at 3% or less.

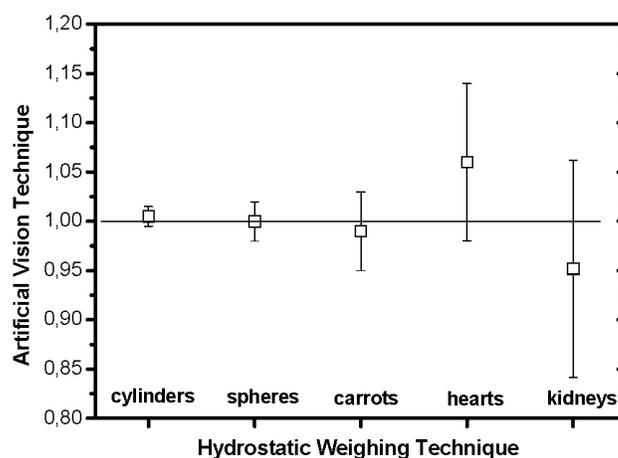


FIGURE 3. Ratio of the average volumes for five different objects measured by AV and HW techniques, respectively.

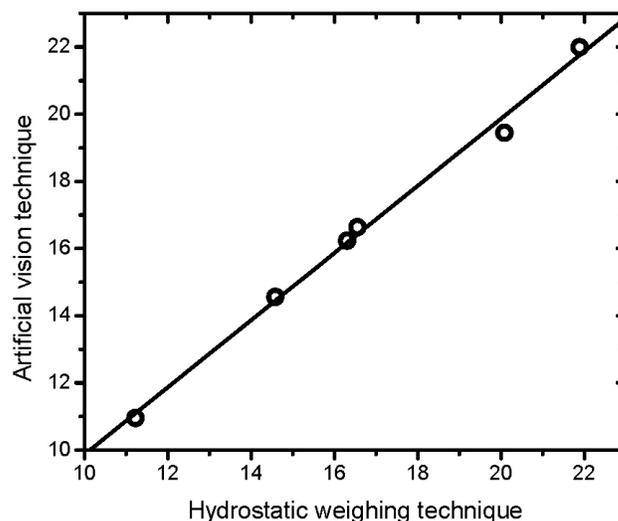


FIGURE 4. Correlation plot between the volume of six different carrots, using the AV and the HW techniques.

### 3. Discussion and conclusions

In order to validate the technique implemented in this work, measurements of average volumes by AV were compared with those obtained by direct measurements through a micrometric caliper and HW technique, respectively. In the first case, the agreement between both measurements was greater than 98% for regular shaped bodies, such as cylinders, while in the second case it was above 95% in most of the cases for non-regular shaped bodies, as is shown in Tables I and II, respectively.

An additional comparative validation of the technique is presented in Figs. 3 and 4. The ratio of average volumes for the five kinds of objects measured by AV and HW techniques, respectively, is shown in Fig. 3, for both regular and non-regular bodies. An inferential statistical analysis, through a *t*-student test with an occurrence probability of 95 %, was also applied to the average volume ratios of the objects.

Furthermore, for the sake of traceability, Fig. 4 shows the correlation between the volumes of six different sizes of carrots, measured by both AV and HW techniques. Note that carrots present a good correlation, even though they are not cylinders. This case shows the plausibility of using the implemented procedure to assess the volume of some oblong parts of the human body, such as arms and legs.

In other words, the results obtained by using AV for volume assessments leads us to conclude that this technique is suitable for the evaluation of spheroid and oblong solid bodies, and presents an uncertainty of about 5% for irregular objects. Likewise, due to the main features of the segmentation technique, which marks boundaries of a digitalized image, some limitations can be found when it is applied to bodies with cavities. On the other hand, we are sure that the AV is a simple technique which could be easily implemented for pedagogical purposes in a course of physics laboratory, being of interest to students of science and engineering.

Finally, it is important to emphasize that, concerning the HW method, used in this study just as a comparison, it is a procedure of direct measurement of volumes, and it is evaluated with the naked eye, inside a graduated vessel. Its uncertainty is only the statistical error incurred by the observer. In our case, an error of 3% was determined.

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