VOLUME ESTIMATION OF SYMMETRICAL OBJECT USING LASER LIGHT SECTIONING

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ABSTRACT
This paper presents a method to estimate volume from three-dimensional characteristics of symmetrical objects by computer vision system using laser light sectioning. The camera captures the image of laser line projected on the object moving on a conveyor. The captured images can be estimated the widths and heights at various locations along the object. The area of cross section can be integrated to be volume of the object. The image data is extracted from the structured laser light projecting on the surface. After image pre-processing, the laser profile is calculated the center of gravity in order to extract the image coordinate. The homography transformation is used to transform the extracted coordinate to the real world distance (in metric system). A metric vision based on light sectioning for estimating the volume of symmetrical shapes (rectangular shape and circular shape) of the object were tested. The accuracy of estimation can apply in the automatic size grading on the conveyer as well.

KEY WORDS
Laser light sectioning, Machine vision, Metric Vision.

1. Introduction

Normally, the size measurement of various industries such as food processing, fruit and vegetable etc can be determined by weight. Value or price is depended on the size of product. However, some products need to classify size by volume and geometric dimension [1]. The aim of this research is to estimate size of symmetrical objects for applying in the automatic size grading on the conveyer. The non-destructive measurement using machine vision technology can use to estimate the product size optically for on-line inspection and grading systems. The definition of size used here are width, height, length and volume.

Normally, most optical grading techniques use a two-dimensional area projection to estimate the product volume. These methods are subject to measurement volume without thickness data. Therefore, the measurement results are inaccurate. The laser light sectioning method which combines laser triangulation technique with two-dimensional measurement to reconstruct a three-dimensional surface for volume measurement is introduced in this paper. The 3D laser scanner has been implemented in many applications such as surface reconstruction [2], surface modeling and inspections [3][4][6] and geometry measurement [1][9]. The visual servoing based 3D laser triangulation has been used in mobile robot for the navigation system [5].

The structured laser light is used to determine the projective points on the object. The planar metrology and the distance between two planes were applied to determine the widths and the heights of the samples. The technique to measure the geometry using machine vision is called metric vision [8]. Consequently, we can obtain the area and also calculate the volume of the object by integrating the area of cross section. Our scheme presents the measurement of 3-D object from the camera that can be improved to apply in real-time inspecting system.

In this paper, the volume of symmetrical shape samples (rectangular shape and circular shape) of the object was estimated in metric system by mean of laser light sectioning. In the experiment, boxes were used as the rectangular shape and the parts of pipe were used as the circular shape. The simple measurement of dimension using vernier caliper was used to compare with our technique.

2. Principle of operations

2.1 Laser light sectioning system

A red line laser module wave length of 650 nm 16 mW 3VDC (Roithner laser technik, Austria) provides a structured light along the sample through a conveyer system.

![Figure 1. The measurement system](image-url)

The machine vision camera from Basler model SCA 1000 (color 1000x750 pixels) is used to capture the image...
of projected laser on the sample. The conveyor system consists of 24VDC motor and control circuit. This circuit is developed by DS-PIC 16-bit microcontroller for control the speed and direction of DC motor. The measurement system is shown in Figure 1.

2.2 Image processing

The image processing was performed using MATLAB and BCAM driver to acquired image from Basler machine vision camera. The morphological process is used to enhance the image before segmentation process such as image threshold and clear border. The profile extraction is calculated by the principle of center of gravity or first moment [1]. The highest point is the height or the thickness of object and the width of object is distance of the end of part from left or right side. The real world measurement of object must be calibrated from the known dimension object.

\[
p = \begin{bmatrix} x \\ y \\ w \end{bmatrix}
\]

(1)

In two dimensions, the homography projection \( H \) of \( p \) to a point \( p' \) on another plane can be formulated as

\[
p' = Hp
\]

(2)

\[
p' = \begin{bmatrix} x' \\ y' \\ w' \end{bmatrix}
\]

(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,

\[
\begin{bmatrix} x' \\ y' \\ w' \end{bmatrix} = \begin{bmatrix} h_{11} & h_{12} & h_{13} \\ h_{21} & h_{22} & h_{23} \\ h_{31} & h_{32} & h_{33} \end{bmatrix} \begin{bmatrix} x \\ y \\ w \end{bmatrix}
\]

(4)

One of the nine parameters with in \( H \) 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,

\[
x_i' = \frac{h_{11}x_i + h_{12}y_i + h_{13}}{h_{31}x_i + h_{32}y_i + h_{33}},
\]

\[
y_i' = \frac{h_{21}x_i + h_{22}y_i + h_{23}}{h_{31}x_i + h_{32}y_i + h_{33}}
\]

(5)

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

\[
\begin{bmatrix} x_1 & y_1 & 1 & 0 & 0 & x'_1x_1 & x'_1y_1 & x'_1 \\ : & : & : & : & : & : & : & : \\ x_4 & y_4 & 1 & 0 & 0 & x'_4x_4 & x'_4y_4 & x'_4 \\ 0 & 0 & 0 & x_1 & y_1 & 1 & y'_1x_1 & y'_1y_1 & y'_1 \\ : & : & : & : & : & : & : & : \\ 0 & 0 & 0 & x_4 & y_4 & 1 & y'_4x_4 & y'_4y_4 & y'_4 \end{bmatrix} = \begin{bmatrix} h_{11} & 0 \\ h_{12} & 0 \\ h_{13} & 0 \\ h_{21} & 0 \\ h_{22} & 0 \\ h_{23} & 0 \\ h_{31} & 0 \\ h_{32} & 0 \\ h_{33} & 0 \end{bmatrix}
\]

(6)

The solution of the homography matrix can be determined by 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 \( p \).

![Figure 2. The image processing flow chart](image)

2.3 Metric vision

The planar metrology is the metric vision method to measure the geometry on plane [7][8]. We must know the real world data being the reference coordinate as shown in figure 3 (the measuring calibration grids).

In two dimensions, the homography matrix maps the homogeneous point from the homogeneous coordinate as follows. A point in the plane is defined in homogeneous coordinates as

![Diagram of homography matrix](image)
2.4 Volume estimation of symmetrical object

A symmetrical shape is shapes, which can be divided in two parts with exact the same size (see figure 6). Therefore, we can calculate the half-area to determine all area of the object. The laser profile on rectangular object and circular object are shown in figure 4 and figure 5, respectively. The volume of them can be determined by integrating the area of cross section (see equation 7, equation 8, and equation 9) along the length of object. The calculation has to be concerned with the conveyer speed. (See equation 10)

\[
\text{Area of rectangle } = ab \quad (7)
\]

\[
\text{Area of circle } = \pi \frac{a^2}{4} \text{ or } \pi \frac{b^2}{4} \quad (8)
\]

\[
\text{Area of ellipse } = \pi \frac{ab}{4} \quad (9)
\]

\[
\text{Volume } = \sum_{n=1}^{L} \text{Area}_n \quad (10)
\]

3. Experimental results

In the experiment, the three pieces of box were used as the rectangular shape and the three pieces of pipe were used as the circular shape. The example of ellipsoid object has been presented in the previous work [9]. The simple dimension measurement using vernier caliper was used to compare with our technique.

<table>
<thead>
<tr>
<th>Object No.</th>
<th>Metric vision Height (mm)</th>
<th>Vernier caliper Height (mm)</th>
<th>Error (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>40.7</td>
<td>41.4</td>
<td>1.67</td>
</tr>
<tr>
<td>2</td>
<td>58.8</td>
<td>60.4</td>
<td>2.51</td>
</tr>
<tr>
<td>3</td>
<td>80.1</td>
<td>80.5</td>
<td>0.43</td>
</tr>
<tr>
<td>4</td>
<td>34.1</td>
<td>34.1</td>
<td>0.05</td>
</tr>
<tr>
<td>5</td>
<td>47.1</td>
<td>48.4</td>
<td>2.71</td>
</tr>
<tr>
<td>6</td>
<td>58.2</td>
<td>59.5</td>
<td>2.12</td>
</tr>
</tbody>
</table>

Maximum Error 2.71
Minimum Error 0.05
Average Error 1.58
STD Error 1.11
According to table 1, 2, 3 and 4, the error analysis of experiment results is demonstrated that the percentage of maximum error of height, width and length are 2.72%, 2.42% and 2.71%, respectively. The percentage of minimum error of height, width and length are 0.05%, 0.42% and 1.03%, approximately. The average error of height, width and length are 1.59%, 1.35% and 1.62%, respectively and the standard deviation are 1.11%, 0.82% and 0.67%, respectively. The experimental results of height and width for calculating the area cross-section can be acceptable. The percentage of maximum error of volume is 13.13% and the average of volume error is 6.16%. However, accuracy of volume estimation is low because of the accumulation error from area cross section to formulate the volume along to conveyer.

4. Conclusion

This technique is capturing a structured laser light of object in a single view with a machine vision camera, and then processed with a self developed program in MATLAB software. The principle of image processing and metric vision method is applied to calculate width, height, length as well as the volume of the object along the conveyer. The height, width and area cross section are corresponding to the size of object. Moreover, each of area cross section along the object can be calculated to the volume. However, the speed of conveyer must be stable and the measurement computation must be fast enough corresponding to the conveyer speed. This system could be benefit to design the automatic grading machine and non destructive measurement in the future.

References