'87 KACC 1987.10.16～17

MEASURING THE VOLUME OF POWDER BY VISION

Seiji Ishikawa*, Shigeru Harada**, Hiroyuki Yoshinaga***, and Kiyoshi Kato*

* Department of Computer Science, Faculty of Engineering, Kyushu Institute of Technology, Tobata, Kitakyushu 804 JAPAN
** Kumamoto Technical High School, Yatsushiro 866 JAPAN
*** Research and Development Division, Seikosha Co., Ltd., Tokyo 130 JAPAN

Abstract: This paper describes a technique for measuring the volume of a pile of powder in a visual way. The volume of a fragile object whose shape is easily transformed by a slight touch of another object must be measured without any contact with it. This can be achieved by applying a three-dimensional shape reconstruction technique employed in computer vision. We have developed a measurement system that finds the volume of a pile of powder by employing a range finder, and performed an experiment of determining the volume of PVC powder piled on a table. The result of the experiment was satisfactory.

1. Introduction

Powder or particulate matter has long been the subject of research[1], since it has close relation to human life. Among many aspects of research on powder engineering, the present paper focuses its attention on the measurement of the volume of a pile of powder. Bulk density of powder is defined as the weight of the powder devided by its bulk volume which is measured by a graduated cup[2]. However, once the powder is emptied on a table out of the graduated cup, the piled powder receives an alteration in its density. This is because the volume of powder usually changes dependent upon its shape. Therefore when one needs determining the volume (and the density) of an arbitrarily shaped pile of powder, the measurement should be performed without any contact with the powder. This can be achieved by employing a reconstruction technique of three-dimensional solids often used in computer vision.

In the field of computer vision, reconstruction of a three-dimensional object from its two-dimensional images is vital for the recognition of the object. Two main reconstruction techniques are surveyed by Magee and Aggarwal[3]: one employs stereopsis, while the other uses a range finder, which is our present concern. A range finder projects a slit light onto an unknown object and recovers the three-dimensional coordinates of every sampled point on its illuminated surface. Shirai[4] employs the technique for recognizing polyhedra in a scene. Agin and Binford[5] describe the shape of curved objects by the technique. Recently several improvements in a range finder have been made, but we do not enter into this respect here.

In the present paper, a technique is described for measuring the volume of a pile of powder by employing a range finder. The three-dimensional shape of the powder on a table is reconstructed by the range finder, and its volume is calculated by applying numerical integral. Experimental results are also shown on the measurement of the volume of PVC powder. Performance of the proposed technique is discussed and the problems to be studied are given.

2. The Measurement System of Powder Volume

The proposed system determines the volume of arbitrarily piled powder. As is easily seen later, the objects measured are not necessarily restricted to powder. However our attention is focused on a fragile material such as powder, since determining the volume of a fragile material is of difficulty unless the proposed non-contact measuring technique is employed.

2.1 Equipment of the System

The equipment of the system includes a micro computer, a TV camera, an image input device, a slit projector, and some other subsidiary peripherals (See Fig.1). The powder whose volume is to be determined is piled on a table, and the slit projector projects a slit light onto it. This yields a light stripe on the surface of the powder. By changing the location of the slit projector step by step by a constant interval, a slit light is projected systematically onto the powder from one end to the other, and each time the projection is performed, the TV camera takes its picture. The micro computer processes these pictures to determine the volume of the powder.

2.2 Process of the Measurement

The measurement process consists of three main parts: calibration of the measurement system, acquisition of the light stripe images of the powder to be measured, and calculation of its volume. The flow of the process is given in Fig.2.

2.3 Calibration

The proposed measurement technique recovers the three-dimensional shape of a piled powder by employing a range finder. For the recovery, the relation must be formulated between the image plane of the TV camera and the three-dimensional

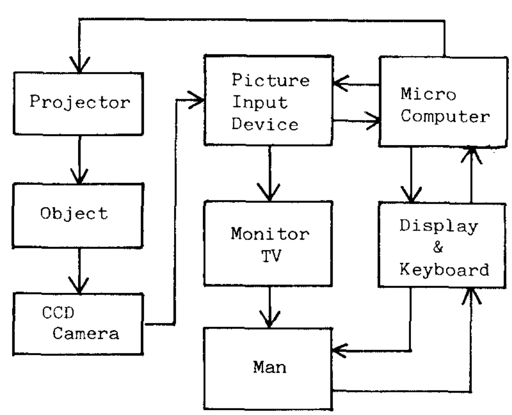


Fig.1 The block diagram of the measurement system.

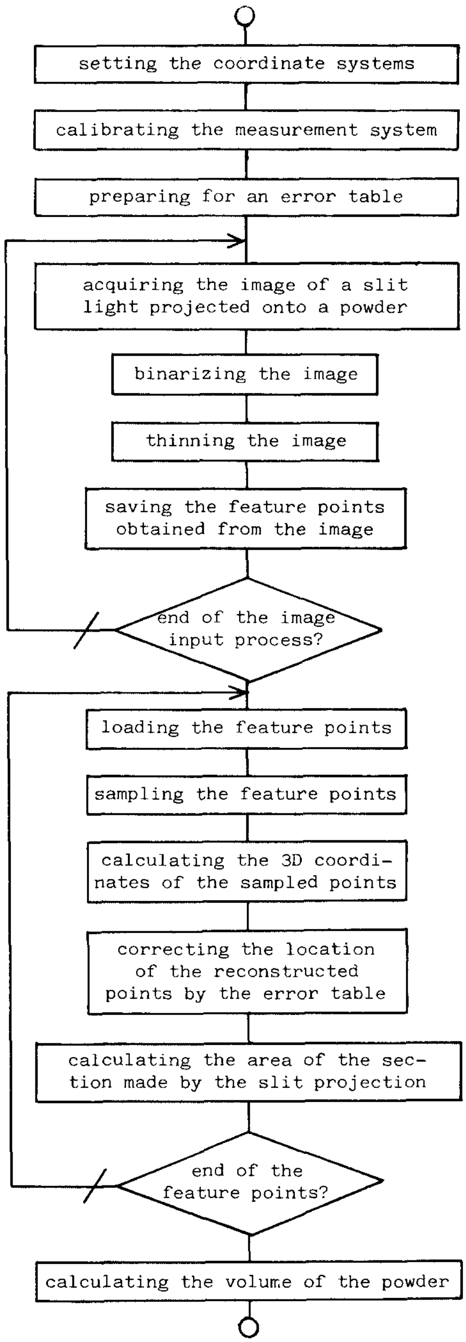


Fig.2 Flow of the measurement.

space where measured objects exist. Let us establish the XYZ coordinate system in the three-dimensional space and the xy coordinate system on the image plane (See Fig.3).

Suppose that the XY plane is transformed into the image plane by the two-dimensional projective transform. Then the point (X, Y, 0) in the three-dimensional space relates to the point (x, y) on the image plane by

$$(\alpha X, \alpha Y, \alpha) = (\beta x, \beta y, \beta) \begin{pmatrix} b_{11} & b_{12} & b_{13} \\ b_{21} & b_{22} & b_{23} \\ b_{31} & b_{32} & b_{33} \end{pmatrix} , \quad (1)$$

where α, β, and b_{ij} $(i,j=1,2,3)$ are constants $(\alpha, \beta \neq 0)$. By Eq.(1), we have

$$X = \frac{b_1 x + b_2 y + b_3}{b_7 x + b_8 y + 1} ,$$
$$Y = \frac{b_4 x + b_5 y + b_6}{b_7 x + b_8 y + 1} , \quad (2)$$

where $b_1 = b_{11}/b_{33}$, $b_2 = b_{21}/b_{33}$, $b_3 = b_{31}/b_{33}$, $b_4 = b_{12}/b_{33}$, $b_5 = b_{22}/b_{33}$, $b_6 = b_{32}/b_{33}$, $b_7 = b_{13}/b_{33}$, and $b_8 = b_{23}/b_{33}$. The coefficients in Eq.(2) can be determined by employing the least square method, if only a set of points on the XY plane and their corresponding points on the image plane are given.

Since the point reconstructed by Eq.(2) usually contains a locational error caused by the aberration of the TV camera lens, the reconstructed point needs to be corrected with its location. An error table is prepared for this purpose which keeps the locational error at every base point on the XY plane. Each time a point is reconstructed on the XY plane, its locational error is calculated by the interpolation employing those values at the four nearest base points around it, and then the point is given the correction.

2.4 Picture Processing

The projector projects a slit light onto a pile of powder. The slit light yields a light stripe on the surface of the powder, and this scene is taken a picture by the TV camera. Since the slit light is set to have enough intensity to distinguish the light stripe from the background, the picture is binarized to extract only the light stripe. The picture then receives thinning process, and the resultant pixel sequence on the thinned light stripe is saved in the computer as a set of feature points on the powder extracted by the slit light projection.

Each time a slit light is projected onto the powder, the feature points are obtained, and this finally gives the whole shape of the powder to be measured.

2.5 Calculation of the Powder Volume

In the first place, the points on the surface of the powder are reconstructed from the data obtained by the picture processing. Let us denote a feature point on a thinned light stripe by p(x, y), its corresponding point in the XYZ coordinate system by P(X, Y, Z), and the projection center where the TV camera exists by $O(X_0, Y_0, Z_0)$. Fig.3 illustrates the relation between these points. In Fig.3, the points $Q(Q_x, Q_y, 0)$ $R(R_x, 0, R_z)$, and $S(S_x, 0, 0)$ exist on a slit plane containing the slit light of the projector, and P'(X', Y', 0) is the point where the extension of the line segment Op intersects the XY plane. Given p(x, y), the point P' is obtained

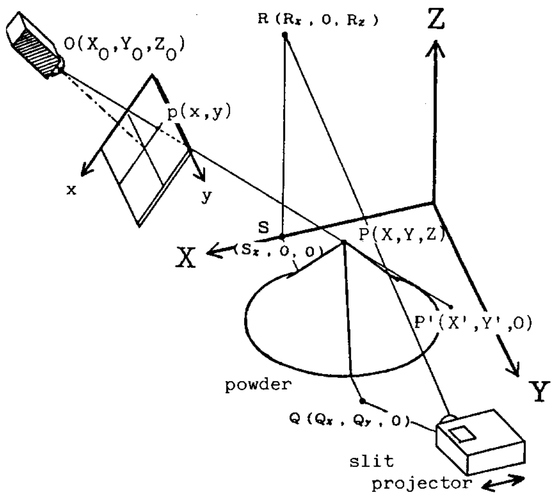


Fig.3 A slit light and the coordinate systems.

from Eq.(2) by two-dimensional projective transform. Suppose that the coordinates of the points O, Q, R, and S are known. Then the line segment OP' is given in the form

$$\frac{X - X'}{X_0 - X'} = \frac{Y - Y'}{Y_0 - Y'} = \frac{Z}{Z_0} . \qquad (3)$$

On the other hand, the slit plane made by Q, R, and S is written as

$$Q_y R_z X + (S_x - Q_x) R_z Y + (S_x - R_x) Q_y Z = Q_y R_z S_x . \qquad (4)$$

Since the point P is the intersection between the line segment OP' and the slit plane, by employing Eqs.(3) and (4), P is given in the form

$$X = (X_0 - X')t + X',$$
$$Y = (Y_0 - Y')t + Y', \qquad (5a)$$
$$Z = Z_0 t,$$

where

$$t = \frac{(S_x - X')Q_y R_z - (S_x - Q_x)Y' R_z}{(X_0 - X')Q_y R_z + (Y_0 - Y')(S_x - Q_x)R_z + Z_0(S_x - R_x)Q_y} . \qquad (5b)$$

Thus the location of the point on the powder is recovered in the three-dimensional space.

The volume of the powder is calculated by making use of numerical integral. Suppose that a slit plane is given by $X = kd$, where $k = 1,2,3,\ldots,n$ (n:odd), and d is a positive constant denoting a translation interval of the projector. If we denote the recovered points with respect to the k'th projection of a slit light by P_{ki} (X_{ki}, Y_{ki}, Z_{ki}) $(i=1,2,\ldots,m_k,\ m_k$:odd), the area S_k of the section of the powder cut by the k'th slit plane is expressed by the Simpson's method in the form

$$S_k = \frac{h}{3} \sum_{i=odd}^{m_k - 2} (Z_{ki} + 4Z_{k,i+1} + Z_{k,i+2}) .$$

Here h(>0) corresponds to a sampling interval. Given $S_1, S_2, \ldots, S_n$, the volume of the powder is then calculated by the following equation:

$$V = \frac{d}{3} \sum_{k=odd}^{n-2} (S_k + 4S_{k+1} + S_{k+2}) .$$

3. Experimental Results

An experiment was performed on the measurement of the volume of a pile of PVC powder by the proposed technique. The measurement process was automated from the acquisition of slit images of the powder to the calculation of its volume, and the whole process took about fifteen minutes except for the calibration time. Table 1 shows the result of the measurement with respect to a rigid object whose volume can be found by employing a measuring tool or by the volume of the water which the object excludes. Table 2, on the other hand, shows the result of the measurement with the PVC powder piled on a table. The PVC powder was first determined its volume by a graduated glass cup. Then it was emptied out of the cup on the table and the volume was measured by the proposed technique. Both measured values are given in Table 2 for comparison. The synthesized slit images in Fig.4 illustrate the shape of the PVC powder corresponding to each case in Table 2.

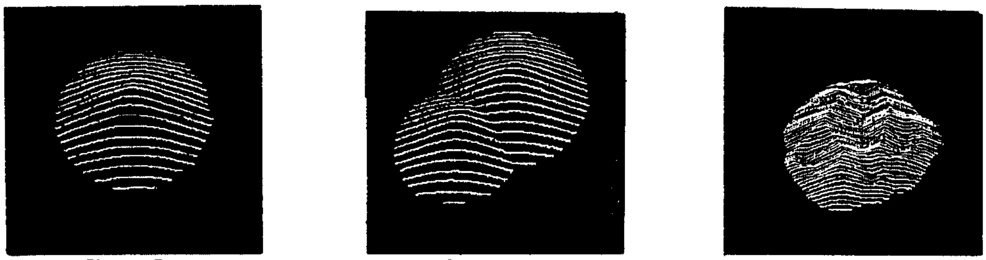
The two-dimensional projective transform (Eq.(2)) was defined by 156 base points placed at equal spaces (20mm) on the base plane (the XY plane). Fig.5 illustrates the distortion of the base plane obtained from the projective transform. The distortion was the largest at the origin : -14mm along the X axis, and -10mm along the Y axis.

Table 1 The result of the measurement.

	the real value (cm^3)	the measured value (cm^3)
Block	1000	1006
Plaster Model	495	502

Table 2 The result of the measurement.

	the value measured by a graduated glass cup (cm^3)	the value measured by the proposed technique (cm^3)
Shape I	500	547
Shape II	700	754
Shape III	500	588



Shape I　　Shape II　　Shape III

Fig.4 Synthesized slit images of the measured powder.

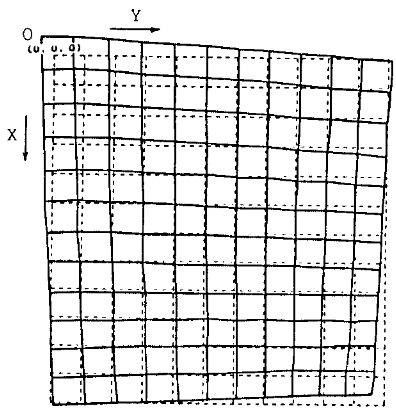


Fig.5 Distortion of the base plane.

4. Discussion

The result of the experiment was satisfactory The error contained in the measured volume by the proposed technique is within a few percent in the case of rigid objects as is seen in Table 1. On the other hand, in Table 2, the values of the volume measured by the proposed technique exceed those measured by a graduated glass cup by about ten percent. This is because the bulk volume of the PVC powder increased after it was emptied on the table from the galss cup. Therefore the values obtained by the proposed technique in this case are estimated to approximate the true values within the precision comparable to the case of rigid objects, although the precision may also depend on the complexity of the shape of the piled powder.

Since a camera lens generally contains aberration, it causes distortion on a base plane with which the measurement system is calibrated. As this distortion has direct influence on the precision of the measurement, an error table was introduced in the experiment to compensate the distortion. This yielded the satisfactory results.

In the present measurement system, the slit projector looks at the measured powder by a dip of 50°. This might still produce invisible parts on the surface of the piled powder that has hilly shape. This problem will however be solved, if the slit light is projected from right above the object.

The proposed system determines the volume of piled powder without any contact with it. As stated before, the object to be measured is not restricted only to powder or particulate matter. However the application of the proposed technique to those fragile objects seems most appropriate, if its non-contact nature is taken into account.

Analysis of the factors that have influence upon the precision of the present technique, the quantization error of the slit images, sampling intervals, for example, still remains to be studied.

5. Conclusion

A technique was presented for determining the volume of piled powder visually. A range finder was introduced to reconstruct the shape of the powder, and the method of numerical integral was employed for the calculation of its volume. Although the application of the proposed technique is not restricted to powder or particulate matter, the non-contact nature of the technique will well be demonstrated in the measurement of those fragile objects. Further analysis on the precision of the present technique remains to be studied.

Acknowledgement

The authors are thankful to Prof. Yuu of Kyushu Institute of Technology for his valuable suggestions.

References

[1] C. Orr Jr. and J. M. Dalla Valle: Fine particle measurement, The Macmillan Company (1959).

[2] S. Miwa: Powder and particulate engineering, Asakurashoten (1972).

[3] M. J. Magge and J. K. Aggarwal: "Using multisensory images to derive the structure of three-dimensional objects — A review", Comput. Vision, Graphics, Image Process., 32, 145-157 (1985).

[4] Y. Shirai: "Recognition of polyhedrons with a range finder", Pattern Recognition, 4, 243-250 (1972).

[5] G. J. Agin and T. O. Binford: "Computer description of curved objects", IEEE Trans. Comput., C-25, 439-449 (1976).