RESEARCH ON MICRO - STEREOPHOTOGRAMMETRY

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ABSTRACT

This paper deals with the related theory of micro-stereophotogrammetry and the experiments made on frog-ova. In this paper, the method of obtaining the matchable pairs of stereoscopic pictures by using a stereomicroscope, and of solving the marked points on the surface of a frog-ovum and their variational track and velocity using three analytical treatments are presented. With Planicomp C-100, an analytical Plotting instrument, work of surveying has been performed to collimate the stereomodel statically, to record the numerical data and to draw the contour automatically through joining dozens of points recorded on the contour level with the help of the spline function.

Experiments have shown that microstereophotogrammetry can be efficiently used to carry out a three dimensional analysis of tiny specimens. Practice has demonstrated that the theories and methods which tests were based on are simple and accurate, and micro-stereophotogrammetry can be used to advantage when applied to microorganism science, medical science and other subjects.

1. INTRODUCTION

The development of micro-stereophotogrammetry has paved the way for a vaster field of application of photogrammetry. Micro-stereophotogrammetry has been proved to be effective in a number of cases. It has been used to determine the geometric shape of a tiny grain of a building material and its surface defects, a microbic cell, an insect ovum, as well as the ecocline of bacteria in medicine.

Following is the initial test of measuring a frog-ovum by the use of micro-stereophotogrammetry.

2. STEREOMICROSCOPIC PHOTOGRAPHY

The optical system of a stereomicroscope is shown in Fig. 1.

The process of getting stereopairs with a stereo-microscope is illustrated as below:

First, select a table with either a black or a white surface according to the color of the object and put the object in the center of the table. Then rotate the working handwheel and adjust the eyepiece to such a degree that the image of the object reaches its clearest form. Next dial the turutable and adjust the magnification of the zoom objective to get a proper image. The magnification of the zoom objective can be read from the readout ring. Then set the box of the conventional 135 camera to the eyepiece of the stereo-microscope to take photo of the specimen.

3. THE PROCESS OF MICROPHOTOGRAMMETRY

Method 1. The height of an object is solved by the elevation on the specimen stage and the planimetric coordinate is derived from the rectangular cells.

In taking stereomicrophotographs, a regular grid (mesh copper grid, grating grid) with an interval of 0.05mm is used to determine the model scale and the planimetric coordinate.

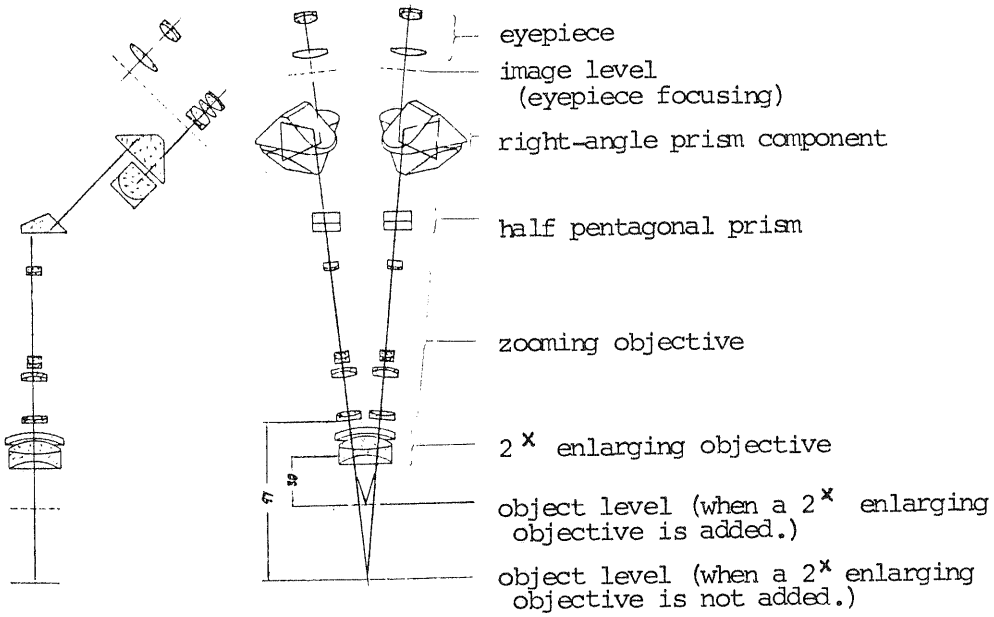

Fig. 1

Formulas to be used:

$$X = M_x \qquad x = x' - M_{ox} \tag{1}$$
$$Y = M_y \qquad y = y' - M_{oy}$$

where. M = a photosacle denominator,

x , y = measuring coordinates on the negative film,

x', y' = the coordinates of the instrument,

M_{ox}, M_{oy} = the zero seats of the instrument.

The known elevations on the specimen stage are put to use at solving the height (using a conventional microscope for photogrammetry). The equation below is used to calculate the photographed height of a tiny object.

$$\Delta h = K \Delta h_0 \tag{2}$$

where $$K = \frac{p_i - p_0}{p_i' - p_0'} = \frac{\Delta p}{\Delta p_0}$$

Δp = the horizontal differential parallax of the point to be located,
Δp_0 = the horizontal differential parallax of the known elevation,
Δh_0 = the known elevation.

Method 2. Determination of the height of a point with an object distance (H)

As the photograph taken with a stereomicroscope is a photograph of central projection so the relevant formula from photogrammetry could be used.

$$\Delta h = h = H \cdot \frac{\Delta p}{p} \tag{3}$$

where H = the distance from the nodal point of incidence to the object plane.

Method 3. Direct linear transformation (DLT) method

$$x = \frac{L_1X + L_2Y + L_3Z + L_4}{L_9X + L_{10}Y + L_{11}Z + 1}$$

$$y = \frac{L_5X + L_6Y + L_7Z + L_8}{L_9X + L_{10}Y + L_{11}Z + 1} \qquad (4)$$

With the DLT formula to solve the problem, it is necessary to fix up more than six control points not lying on the same plane. It is required that a specimen panel with six uneven control points be made beforehand and arranged in the sighted scope on the workbench. Then the tiny object to be photoed is put on it. The object is observed and photographed through the microstereoscope. In making the specimen panel, its elevation should not exceed the depth of field scope of the microscope.

4. TEST

In this test we separately determined the signalized points on the surface of a frog-ovum and its variational velocity and we also made an isoline map of the frog-ovum.

4.1 The Determination of the Three Dimensional Coordinating Signalized Points on a Frog-ovum Surface

The frog-ovum was laid on a mesh copper grid with an interval of 0.1 mm and line diameter of 0.3 mm. Between the copper grid and the frog-ovum there was coated a thin layer of agar-agar to prevent the frog-ovum from slipping off. Eleven signalized points were set on the surface of the frog-ovum then the stereophotographs of the frog-ovum were taken every two minutes. Altogether 12 image pairs were taken. The picture scales are 8.5:1, 25:1 and so on.

In order to test the variational regularity (differential velocity), every eleven signalized points in the twelve image pairs were measured separately with the stereo comparator 1818. Then by making use of the method 1 (the elevations are separately No. 1: 0.38322 mm, No.2: 0.56767 mm, No. 3: 0.96524 mm, No. 4: 1.3205 mm) and the method 2 (H = 95 mm), the height of the signalized points on the specimen of the frog-ovum was calculated individually. Using the two methods mentioned above, the eleven signalized points on the image pair No. 21-22 were solved. Then comparing the two methods we found the mean square errors were $M_X = \pm 0.93$ μm, $M_Y = \pm 0.84$ μm, $M_Z = \pm 1.08$ μm. The height of the four signalized points was obtained by using the two methods and was compared with the known height. The results are listed in Table 1. The mean square errors are separately $m_{h_1} = \pm 1.02$ μm (in method 1), $m_{h_2} = \pm 1.09$ μm (in method 2). By using the measurements on Pictures 21-22, the three dimensional coordinates of the signalized points on the ovum were determined through the DLT formula (the control points were set out along the sides as shown in Fig. 2). The coordinates calculated through the DLT method were compared with those calculated through grids and elevations (see Table 2). The mean square errors are $m_X = \pm 0.92$ μm, $m_Y = \pm 0.83$ μm, $m_Z = \pm 0.96$ μm.

The variational velocity can be obtained from the three dimensional coordinates of the signalized points through the following formula.

$$V = S / t \qquad (5)$$

where.

$$S = \sqrt{\Delta X^2 + \Delta Y^2 + \Delta Z^2}$$

t = time interval (second).

Table 1

Points No.	ΔX (μm)	ΔY (μm)	ΔZ (μm)	Known Height (mm)	Method 1 Calculated Height (mm)	Method 2 Calculated Height (mm)
d_3	1.0	0.0	1.0	No 1:0.38322	0.38370	0.382991
d_2	1.0	0.0	0.0	No 2:0.56767	0.56788	0.56879
d_1	1.0	1.0	1.1	No 3:0.96524	0.96341	0.96410
b	0.0	1.2	0.2	No 4:1.32050	1.32177	1.32200
c	1.0	0.2	1.0			
a	1.0	0.3	0.7			
g	1.1	1.2	0.5			
f_3	0.9	0.7	0.3			
f_2	0.9	0.8	0.7			
f_1	1.0	0.9	0.8			
e	1.1	1.3	3.0			
m_x=±0.93μm	m_y=±0.84μm	m_z=±1.08μm			m_{h_1}=±1.02 μm	m_{h_2}=±1.09 μm

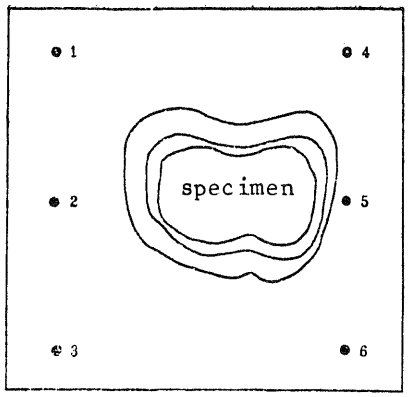

Fig. 2 The layout of control points

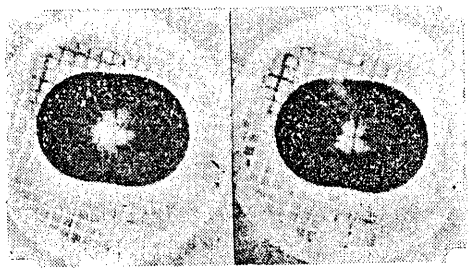

Fig. 3

Table 2

Point No.	ΔX (μm)	ΔY (μm)	ΔZ (μm)
d_3	0.1	0.1	0.1
d_2	2.3	0.3	0.2
d_1	1.0	0.2	0.3
b	0.6	1.1	0.3
c	0.3	0.9	1.1
a	0.2	1.9	0.6
g	0.1	0.3	0.7
f_3	0.8	0.4	1.0
f_2	0.9	0.2	2.0
f_1	0.2	0.8	1.1
e	1.1	0.9	1.3
	m_x= ±0.92 μm	m_y = ±0.83 μm	m_z = ±0.96 μm

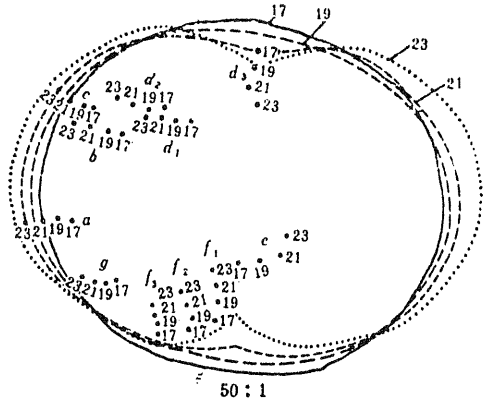

Fig. 4

Notes: a,b,c... g — the serial number of the signalized points
17,19,21,23 — the serial number of the photographs of the Frog-ovum taken every two minutes

Table 3

Point No.	Variational Velocity V(mm/sec)
a	0.00045
b	0.00064
c	0.00044
d_1	0.00046
d_2	0.00055
d_3	0.00075
e	0.00088
f_1	0.00061
f_2	0.00051
f_3	0.00035
g	0.00034

The average variational velocity on each point is shown in Fig. 3. It is easy to make out that the points at a high position posses a faster variational velocity than those at a low position. Furthermore, the change goes on slowly at the beginning and then speeds up. Fig. 3 shows an enlarged photographic map of a frog-ovum on Pictures 21 and 22 (enlarged by 25 times). Fig. 4 shows the variational track of the 44 points in three image pairs.

4.2 Making Isoline Maps of the Frog-Ovum

The isoline maps were made with Planicomp C-100. The distances of the fiducial marks measured on the diapositive plate were taken as the distances of the fiducial marks in the x, y directions. To give the inner orientation, f = 22 was fed into a computer. The position of the principal points on the photo was calculated through the following equation

$$x_{c_0} = \frac{x_3 - m_{34}\left((y_3 - y_1) + m_{12}x_1\right)}{1 - m_{12}m_{34}}$$

$$y_{c_0'} = \frac{y_1 - m_{12}\left((x_1 - x_3) + m_{34}y_3\right)}{1 - m_{12}m_{34}} \qquad (6)$$

where: x_i and y_i = the measured coordinates of the fiducial marks.

$$m_{12} = \frac{y_2 - y_1}{x_2 - x_1} \qquad m_{34} = \frac{x_4 - x_3}{y_1 - y_3}$$

But, the photographic affine deformation has to be considered with Planicomp C-100. The corrected equation of the image coordinates (x,y) is:

$$x' = x \cdot K_x \cos\kappa - y \cdot K_y \cdot \sin\kappa$$
$$y' = x \cdot K_x \sin\kappa + y \cdot K_y \cdot \cos\kappa \qquad (7)$$

where: K_x , K_y = coefficient of extension in the x, y directions of the photos.

κ = angle of rotation for the coordinate system of the photos

Then the relative orientation was given. In this test the parallaxes y of eight points were measured. The setting parameters in the model coordinate szstem of the photos were calculated by the measurements, i.e. the relative orientation of image pairs. After making calculations in due order for approximation, there still existed a parallax of 0.01 mm in the results of orientation at the display terminal. This is chiefly due to the inaccuracy in the distance of f and of the fiducial marks. Absolute orientations were performed through the program of individual model orientations. The leveling of models was set by the grids on the diapositive plate. In making the survey, the coordinates x,y,z of four grid points were first fed into a computer. Then, the points, the table orientation and the isoline of the frog-ovum were plotted and mapped on the model scale of 1:10, and on the drawing scale of 1:2. Since the negative film had been enlarged 8.5 times and the observation system of Planicomp C-100 had also been enlarged 8 times. The degree of clearness of the model was poor and so it was more difficult to draw the isoline by using the tracking method. Therefore, work of surveying was done on the contour level to collimate the stereomodel statically and to record the data autographically. The isolines were mapped out automatically by joining tens of points recorded on the contour level in accordance with the program with the help of the spline function. Because the frog-ovum lying on the specimen panel looks like a tiny egg and the observations (or photographs) were taken from top to bottom. We can only see the upper part and the middle part of the ovum. The isoline of the lower ovum can not be drawn. The height reading of the frog-ovum on the model was about 6.62 mm. An isoline was drawn every 0.5 mm (from 3.5 mm — 6.5 mm on the engraving membrane). Seven isolines were drawn in all. The isoline map of the frog-ovum was shown in Fig. 5 (image pairs 21-22). From this test we can see that the coordinates of the points were obtained by using the three methods which are basically the same. But when using the DLT formula, we must have more than six control points to solve the eleven L coefficients and we must lay more than six signalized points on the specimen panel of the microscope, which is difficult to do now.

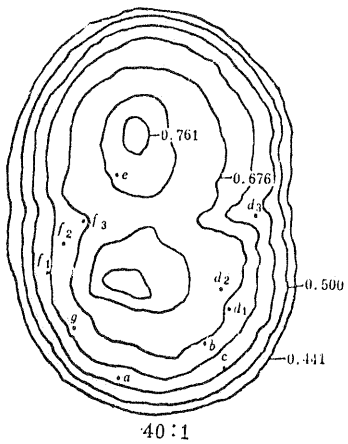

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Fig. 5

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