3D MAPPING OF DARK AND COMPLICATED OBJECTS BY RASTERSTEREOGRAPHY

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ABSTRACT

Rasterstereography is a photogrammetric method, based on a single photograph of raster lines that are projected on an object. The photograph and the raster diapositive in the projector form together a photogrammetric model of the projected raster lines. Using this technique, people that are not experts in photogrammetry, can perform by themselves, a non-contact 3D mapping of smooth, bright and monotonous objects like small statues. The equipment which is needed for that purpose is a digital camera, a projector, a laptop and a suitable control device. The method is suitable also when the object surface is dark but in this case the raster lines should be wider and the spaces between them bigger. Since only points on the projected raster lines can be measured, it reduced the density of the measured points. The paper presents a method in which the process of projection and photography is repeated from the same angles. The position and direction of the projected raster strip, which are controlled by the computer, are changed slightly each time. This ensure both, the ability to measure and mape dark objects and also the proper density of reference points upon the object's surface.

1. INTRODUCTION

Researchers in archeology, paleontology and some similar branches of science, who carry out field researches need from time to time to compare objects that they have found with similar objects which are located in museums around the world. For this purpose they have to perform all around mapping of the object. Close range photogrammetry seems to be an ideal method for this purpose, especially when the measurements must be contact free. But in many cases the object surface is monotonous, without enough contrast and therefore not suitable for photogrammetric mapping. The old solution for this problem is to add contrast to the object surface by projecting a raster upon it before the photography. Frobin and Hierholzer (1981, 1982a and b), Baj and Bozzolato (1986), Baj and Rampolli (1990) and others, made a further improvement and form the rasterstereograhy. Their idea was to use the raster diapositive in the projector as an additional photograph of the projected raster lines. Together with the single real photograph they form a photogrammetric model of the projected raster lines. That is the way all the information which is needed for 3D mapping of the object is found in the single photograph.
Rasterstereography has five advantages relative to the conventional close range photogrammetry.

1. It suits the 3D mapping of bright and monotoneous objects that usually are not suitable for conventional photogrammetric mapping.
2. There is no need for the special device for simultaneous photography which is essential when the mapped object is moving
3. The black raster lines are easy to identify on the bright image of the object. Therefore it is easy to perform the photogrammetric measurements manually or automatically.
4. There is not need for stereoscopic sight or to identify homologous points in two overlapping photographs. Therefore a non expert in photogtrammetry can study and practice the principles of the method within few hours and make all the mapping, photography and photogrammetric measurements, by himself.
5. The conventional equipment which is needed for the photography and photogrammetric measurements is a digital camera, a suitable control device and a projector. For the improved method which is presented in this paper we use also a laptop and a projector which is connected to the laptop and a control plate, plain white on one of its sides and with grid made of straight lines on the other, it is used for determining the radial distortion of the camera and projector in order to obtain more accurate results.

This method has also five disadvantages.

1. The control device must be prepared by an expert. It contains not only control points but also control planes which their equations in the device coordinates system are known. When an object with a complicated surface is mapped all around, the control device should be plane carefully in order to enable taking many photographs, from different angles.
2. Only the projected raster lines can be measured. As a result, the resolution of the measured points is low and the method is not suitable for surfaces with frequents changes in its topography.
3. Sometimes it is difficult to follow the continuation of the same line on the object and the control planes. Especially when the object surfaces is non continues. Frobin and Heirolzer (1981) cope with the problem by using a raster diapositive in which every tenth line is thicker. Rosenberg et al (1990) used colored raster diapositive but sometimes it does not help.
4. The method is not suitable for dark objects. The dense thin raster lines do not photograph well on dark background. When they are done thicker and more spacious, the resolution and the accuracy of the measured coordinates are reduced.
5. It is not easy to find a metric camera or metric projector. (with distortion less lens). Therefore usually a non metric camera and projector are used. The camera can be calibrated but it is almost impossible to calibrate a slide or overhead projector. Therefore the projected raster lines do not form perfect planes. It effects the accuracy of the rasterstereographic measurements.

In this paper we present an improved method in which the slide or overhead projector is replaced by a laptop and a projector connected to it. It enables to project a single black strip instead of many thin raster lines. After the photography, the projected strip is moved to another position and another photograph is taken. This method of projection has three advantages relative to the old method.

1. The projected strip is well seen even on black object.

2. The two sides of the strip can be found automatically and precisely by procedures of digital edge detection.
3. It is possible to eliminate the effect of the radial distortions of the projector lenses, by planning the projected strip shape.

2. THE RASTERSTEREOGRAPHIC SETUP AND THE CONTROL DEVICE

The rasterstereographic setup and the control device are illustrated in Fig. 1. It is combined of camera and projector which are connected to a laptop and are operated by it, and a control device which the mapped object is located in its center. It is preferable that the more accurate results. directions of the projection and the photography will be perpendicular each to the other or close to that.

The method of computations in rasterstereography is very similar to that of conventional photogrammetry with one difference. Photogrammetry is based on spatial intersection of two lines, each of them is determined by the location of an image on each of the photographs. Rasterstereography is based on the spatial intersection of a line with a plane. The line is determined in the same way by the single photograph. The plane is either that which is formed by a projected raster line or a control plane with known mathematical equation. Therefore the control device has several bright control planes, in addition to the conventional control points. Recommended but not necessary that the control points will have self illumination. The spatial coordinates of the control points are measured with accuracy of 0.1 mm or better because the accuracy of all the rasterstereographic measurements depends on them. The control device is planed so that:

1. It forms a rigid and portable frame.
2. Its size is suitable to the mapped object.
3. The number, orientation, location and size of the control planes are so that the projection of the raster lines is possible from each desired angle. On the other hand, the sections of a raster line which are projected on them are as far as possible from a straight line.
4. The control planes should not disturb the object photography from any desired angle.
5. The number, location and size of the control points are so that at least eight of them, located at the right spatial places are seen from each desired angle of photography.

Figure 1. The rasterstereographic set up consisting of the object under test, a control device, a projector and a camera

Additional part of the control device is a flat calibration plate. One of its sides is plain white, on the other there is a grid of black lines. It is used before the mapping process to determine the radial distortion of the camera and the projector.

3.THE RASTERSTEREOGRAPIC MEASURMENTS AND COMPUTATIONS

3.1. Determining The Cameras Radial Distortions

It is recommended to check the camera's lens distortion before any measurements of new object. The camera lens radial distortions deform the position of the images in the digital photograph by Δx and. Δy . Eq 1 is their mathematical model is given by Brown (1971).

$$
\begin{aligned}
x' &= x - x_p \\
y' &= y - y_p \\
r^2 &= x'^2 + y'^2 \\
\Delta_x &= x'[K_1 r^2 + K_2 r^4 + K_3 r^6 + \ldots] \\
\Delta_y &= y'[K_1 r^2 + K_2 r^4 + K_3 r^6 + \ldots]
\end{aligned}
\qquad (1)
$$

Where x,y are the true image coordinates and the parameters that should be determined are:

xp,yp	the coordinates of the photographs principal point of symmetry
k1,k2,k3 …	the coefficients of radial distortion.

The parameters that their value should be determined are x_p,y_p, K_1,K_2,K_3…

In order to determine the values of the parameters the grid on the calibration plate is photographed. The pair of photo coordinates of the grid corners have to fulfill the following equations.

$$
\begin{aligned}
x_m &= \frac{C_1 X + C_2 Y + C_3}{C_7 X + C_8 Y + 1} - \Delta x \\
y_m &= \frac{C_4 X + C_5 Y + C_6}{C_7 X + C_8 Y + 1} - \Delta x
\end{aligned}
\qquad (2)
$$

where:

C_1,C_2,……C_8	are coefficients
X,Y	are the calibration plate coordinates of the grid corners.
x_m,y_m	are the measured photo coordinates
Δx,Δy	are as in eq.1,

3.2. Determining the projector lens radial distortions.

It is recommended to check the projector's lens distortion any time after the camera's calibration. The projector radial distortion transforms a straight line in the computer coordinate system into a curved projected line. The mathematical model of the distortions is the same as given in eq. 1 and their parameters are determined by an inverse procedure. An ideal grid is formed on the computer screen and projected on the plain side of the calibration plate. Its known image coordinates are inserted as xm,ym coordinates into eq 1 and 2. The projected grid is photographed and the corners photo coordinates are measured, corrected for the cameras radial distortions and inserted to eq. 1 and 2 as the X,Y coordinates. From these equations we obtain the parameters of the projector radial distortions.

Figure 2. A photograph of the object, the control devise and the projected raster lines upon them

3.3. Determining the spatial coordinates of a point upon the object surface, measurements and. computations

This is done in three steps.

3.3.1. Determining the orientation of the digital photograph: This needs to be done for every photograph. The interior and exterior orientations of the photograph are determined simultaneously by calculating the eleven parameters of the DLT equations given by Karara and abdel Aziz (1974).

$$x = \frac{A_1 X + A_2 Y + A_3 Z + A_4}{A_9 X + A_{10} Y + A_{11} Z + 1} \qquad (3)$$

$$y = \frac{A_5 X + A_6 Y + A_7 Z + A_8}{A_9 X + A_{10} Y + A_{11} Z + 1}$$

Where:

$A_1, A_2, \ldots A_{11}$ are coefficients

X,Y,Z are the spatial coordinates of a control point on the control device.

x,y are the photo coordinates of this point corrected for the camera's radial distortions

At least six control points located in the right spatial places are needed in order to determine the eleven parameters.

3.3.2. Determining the equation of a plane formed by a projected raster line: This action is need to be done for each image of a raster line in each photograph/ Several sections of a projected raster line are projected on the device control planes. The spatial coordinates of any point on them, like point A in fig 2 can be determine as follows.

a. Its photo coordinates are measured and corrected for radial distortions.

b. The corrected coordinates x,y are inserted into eq. 3 to obtain the equations of two planes.

$$(A_1 - xA_9)X + (A_2 - xA_{10})Y + (A_3 - xA_{11})Z + (A_4 - x) = 0 \qquad (4)$$

$$(A_5 - yA_9)X + (A_6 - yA_{10})Y + (A_7 - yA_{11})Z + (A_8 - y) = 0$$

c. Together with the known equation of the control plane AX+BY+CZ+D=0 we have the three needed equations to determine the spatial coordinates of point A.

By the same way we obtain the spatial coordinates of points B,C and D and perhaps some additional points similar to them. The spatial coordinates of these points are used to determine the parameters of the equation of the plane, formed by the projected raster line.

3.3.3. Determining the spatial coordinates of a point projected raster line upon the object: The photo coordinates of point like P in Fig 2 are measured and corrected for radial distortions. Two equations of planes are determined like in eq. 4 Together with the known equation of the projected raster line we can determine the spatial coordinates of point P.

4. CONCLUSIONS

It has been shown in this paper that rasterstereography is a simple and effective method for all around non contact measurements and mapping of small objects. All the photogrammetric information of the photogrammetric model is found in a single photograph. There is no need for stereoscopic sight so that also convergent photographs can be used. It increases the accuracy of the measurements, and enables the use of common PC screen as a photogrammetric work station. For these reasons the photography and photogrammetric measurements become simpler and easier for automation. Furthermore the all photogrammetric process, photography and photogrammetric measurements can be carried out by a non expert in photogrammetry. The use of a projector and digital camera which are connected to a laptop improve the quality of the projected raster lines and enable to choose their resolution. Its enable to choose the suitable resolution for the raster lines for better 3D mapping of the object

REFERENCES

Baj, E. and Bozzolato, G., 1986. On line restitution in biosereometrics using one photogram and a metric projector. International Archives Of Photogrammetry And Remote Sensing, Ottawa Canada, 26(5): 271-278.

Baj, E. and Rampolli, M., 1990. Experiments on real time raster photogrammetry. International Archives Of Photogrammetry And Remote Sensing, Zurich Switzerland, 28(5/2): 870-877.

Brown D.C. 1971. Close range camera calibration. Photogrammetric Engineering, 37(8): 855-866.

Frobin, W. and Hierholzer E. 1981. Rasterstereography: a Photogrammetric method for measutment of body surfaces. Photogrammetric Engineering & Remote sensing, 47(12): 1717-1724.

Frobin, W. and Hierholzer E. 1982a. Calibration and model reconstruction in analytical close-range sterephotogtammetry. Part I: mathematical fundaments.. Photogrammetric Engineering & Remote sensing, 48(1): 67-72.

Frobin, W. and Hierholzer E. 1982b. Calibration and model reconstruction in analytical close-range sterephotogtammetry. Part II: special evaluation procedures for rasterstereography and Moire topography. Photogrammetric Engineering & Remote sensing, 48(2): 215-220.

Karara, H.M. and Abdel-Aziz Y.I. 1974. Accuracy aspects of nonmetric imageries. Photogrammetric Engineering, 40(9): 1107-1117.

Rosenberg, N., Zeltser, R., Elad, D., Sahar, M., Avidor, j.M. and Einav, S., 1990. Simplified remote measurement of three-Dimensional Surfaces: Application for Biomedical Engineering, Photogrammetric Engineering And Remote Sensing, 56(9): 12731280