SURFACE MEASUREMENTS OF THE PATTERNLESS OBJECTS WITH VIDEO BASED RASTERSTEREOGRAPHIC SYSTEM

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ABSTRACT

Rasterstereography, which makes use of a projector as one of its camera stations, has been proven to be suitable for surface measurements of the patternless medium sized objects.

A video based system, using the plane constraint approach developed at UNB, together with digital image processing techniques, was configured and tested.

Based on these investigations, successful implementation in industry can be expected. Real-time criteria will not be satisfied at present due to the point identification problem. However, faster results than available from conventional photogrammetry or Moire topography, can be achieved with this system.

INTRODUCTION

"Automation" has become a subject of overall worldwide concern. Like other professions, photogrammetrists are extensively investigating automation schemes, making use of today's solid state electronics and micro-processor resources.

This research focuses on close-range applications, particularly with patternless medium-sized objects. Based on a comparative study of the variants within the family of generalized stereophotogrammetry, rasterstereography is suitable for today's environment.

WHAT IS RASTERSTEREOGRAPHY?

Rasterstereography is a stereophotogrammetric methodology where one of the two cameras is replaced by a projector. Depending on the projected pattern, rasterstereography can be further identified as grid or line rasterstereography (Frobin & Hierholzer, 1982).

WHY USE RASTERSTEREOGRAPHY?

Three major reasons for applying rasterstereography are:

- synchronization;
- reduced digitization work load;
- signalization.

Due to the fact that only one camera is used for "freezing" the information flow onto an image, synchronization of the imaging system is no longer necessary. Because the pattern projection can be digitized beforehand and retained as unchanged during all other measurements, the image coordinate digitization work is reduced to half of the conventional stereophotogrammetric case. Furthermore, signalization of a patternless object is not needed, because the projected pattern can be designed for use as targets.

Another advantage of rasterstereography lies in the automation considerations. Since one "image" consists essentially of a fixed pattern, the feature extration from the digital image is easier than for the conventional stereographic case.

HOW DOES RASTERSTEREOGRAPHY WORK?

The lack of pseudo-image coordinates for control points is the major problem for the processing of rasterstereographic data. However, by implementing certain procedures, the data processing can be done with conventional analytical photogrammetric software.

Frobin et al. (1982) provide a solution with interpolation by identifying the projected points surrounding a control point, measuring all their image coordinates on the camera image and then subjecting these to a perspective transformation.

Another approach has been developed by Ethrog (1987), who utilized two control planes. Raster lines are used for projection. The rear control plane is a flat white plate, while the front plane consists of a frame with several white tapes stretched across, approximately perpendicular to the projected raster lines. With the camera image coordinates, the spatial coordinates of the intersection of the projected raster-lines with the two control planes can be calculated.

Ethrog's method provides a good way for solving the problem of control points on the psuedo photo, and also is capable of compensating for deviations from ideal central perspective transformation. However, while the additional object information provides helpful constraints, especially for the radial distortion control of the projector, it also requires additional work and operation conditions. Therefore, another approach was developed following the same concept in object space design.

THE ONE PLANE CONSTRAINT METHOD

Following Ethrog's approach, the object space control was designed with only one plane, rather than two. Several control points were established on this plane, for which absolute flatness could be assumed (Z = 0). The object was placed in front of the control plane. A regular grid pattern was projected from a projector located on one side, while the camera was set-up at the other, arranged for convergent photography.

Space resection for the camera was performed with the aid of object space control points. The projected raster points on the control plane could then be calculated from the intersections of the bundle with this plane, and these intersected points were subsequently used for the space resection of the projector. An ordinary intersection followed for all other points.

Data processing can be carried out as described above, however, a simultaneous bundle block adjustment may be more favourable. In this case, one extra condition from the plane is added. It can be realized by assigning a constraint function, or better by assigning weighted contraints to the Z coordinates of points located in the plane.

In both cases, the initial values for the orientation parameters can be determined by utilizing a closed solution scheme developed in Shih (1987).

TEST OF ONE-PLANE CONSTRAINT METHOD

TEST OBJECT

In order to evaluate the capability of this scheme, a calibrated satellite antenna was used as test object in a film based system. A surplus flatbed digitizing table provided the control plane.

It is not intended here to imply that this proposed method can be used for ultra-precise surface measurements, such as for antenna calibration, but rather it was intended to use a well calibrated antenna to "calibrate" the proposed system.

REFERENCE DATA

In order to avoid directional reflection from the glass surface, and also to improve the contrast, six sheets of white paper were taped onto the table. Several control points were marked on the paper, and distances between them were measured. All 317 signalized points on the antenna surface had been measured during a geometric analysis project with two Kern E2 electronic theodolites operating in an automated data collection mode (Pedroza, 1987). Based on theorectical derivations, the magnitude of the propagated error in object space in the E-2 system is less than 0.05 mm, which provides for an excellent reference.

DATA ACQUISITION

A Cannon AE-1 camera with a standard 50 mm lens, and a 3-M Model 213 AKD portable overhead projector with 355 mm focal length were used. A grid pattern was generated by scribing onto thick scribing material with the WILD A-10 plotting table using a line-width of 0.6 mm. A contact print diapositive of the grid on Lith-film was used for generating the raster pattern on the projector.

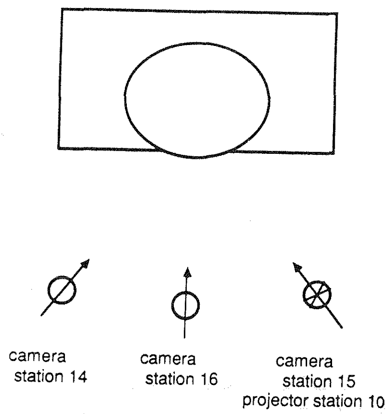

Fig. 1. Test arragnement

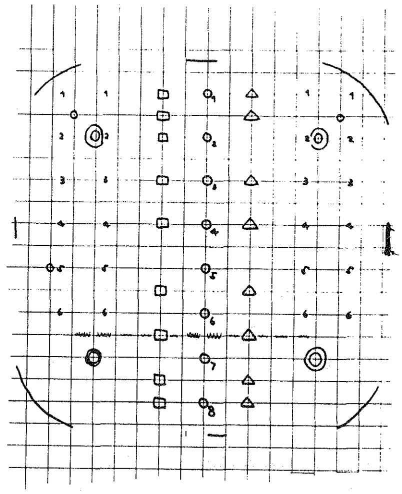

Fig. 2. The pseudo-image

Three photos were taken with different convergence angles (see Fig. 1.), and subsequently digitized on a Zeiss PSK stereo-comparator. At least three readings were taken for each image point. The repeatabilities in terms of RMSE are listed in Table 1, where photo 10 refers to the pseudo image, with its accuracy estimated from the line-width and the precision of the A-10 table.

DATA PROCESSING

The data were processed in three different phases:

- photo-triangulation with 3 real photos;
- single photo space resection/calibration;
- photo-triangulation with pseudo photos.

The first two were accomplished using the object coordinates obtained from E-2 measurements. While the first provided another set of reference data which can be directly used for comparison, the second one was mainly processed for variance analysis. All 317 E-2 points were used to calibrate the non-metric camera imageries, and the 97 projected points were used to calibrate the pseudo image.

In the operating sequence, the single photo space resection/calibration for three real photos was performed first, applying a closed form solution (Shih & Faig, 1987). Then the photo-triangulation with three real photos was performed with the self-calibration program UNBASC2 (Moniwa, 1977). With the resulting object coordinates, the calibration for the projector was performed. Finally, based on the interior orientation parameters from the second phase, the rasterstereographic photo-triangulation was performed with the one-plane constraint and control points in this plane.

RESULTS

- Single photo calibration

In addition to the interior- and exterior orientation parameters, 2 affinity parameters were included. From the resulting parameters, it is evident, that the affine distortion of the real photo is much smaller than the one of psuedo photo. Since the resulting RMSE values are very close to the repeatibility indicator, no further additional parameters were utilized.

Concerning the pseudo photo, with all 97 points scattered around the entire format, the RMSE values are rather large. Further additional parameters were added, but resulted in no significant improvement. It is recognized that these big distortions may not be sufficiently modelled by the additional parameter model used, because of the configuration of the overhead projector. However, the affinity correction was quite effective, especially for the 97 point case.

The case 10b refers to the 33 central point case where the largest radial distance is 45 mm. Although the RMSE values are still larger than expected, they decreased significantly. The magnitude of the affinity parameters is also reduced.

Table 1 : Repeatability of digitization (unit: µm)

photo	10	14	15	16
sx(µm)	(300)	4.0	4.4	3.7
sy(µm)	(300)	4.7	3.9	3.4
scale	1:5	1:60	1:60	1:50

Table 2. The RMSE from single photo calibration

photo	10	10b	14	15	16
sx(µm)	2500	540	3.7	3.6	3.9
sy(µm)	3200	490	3.5	3.7	3.6

(unit: µm)

- Photo-triangulation with real photographs

The resulting average RMSE values in image coordinates from UNBASC-2 are 2µm in x, and 3µm in y. All additional parameters according to Moniwa (1977), i.e., 3 for radial-, 2 for decentering-, 2 for affine distortions, were included.

Furthermore, the plane constraint was used for another accuracy investigation. Since the datum is defined by the E-2 measurements, a plane fitting was performed. The resulting RMSE of the deviation was 0.28 mm, with the largest deviation being 0.56 mm. This accounts for the unflatness of the taped-on paper, and also the relatively poor numerical condition caused by the extrapolation situation. Considering the fact that paper sheets were just taped by their four corners, and that undulation can happen in any place, especially the central part of the paper, this result is quite reasonable.

• The rasterstereographic case

Based on the single photo calibration, the RMSE ratio between pseudo photo and the real photo is near 1:700 for the full format. Following photogrammetric reduction, a 3-D similiarity transformation was performed for fitting to the 3-real-photo case. The RMSE values in planimetry and direction of depth are listed in Table 3.

Table 3. Checking the fit (unit: mm)

Case	Photos	RMSE (plan)	RMSE (depth)	datum
1	14, 16	1	1	plane constraint
2	10, 14	30	16	plane constraint
3	10b, 14	1	1	geodetic definition
4	14, 15, 16	1	1	plane constraint

The accuracy indicated by RMSE of fit, as compared with the single photo calibration, is even worse. However, the central 33 points, as controlled by 6 points whose coordinates were obtained from the 3-real-photo case, present appealing results.

TEST OF VIDEO CAMERA

Presently there are two major types of video cameras, scanning tube and solid-state. For photogrammetric application purposes, solid-state cameras such as CCD or CID type are particularly of interest due to their smaller electronic distortions.

In this study, a Sylvania scanning tube type video camera with autofocus 12-72 mm was used with a Matrox PIP-1024 Image Digitizer Board. An IBM PC/XT compatible with 640K RAM was used as the host. Each "photo" was taken by averaging 4 successive images to reduce some of the distortions. The converted image contains 512x480 pixels. Two test objects were utilized, a plate with bolts and a board with crosses.

Three approaches were configured. One follows El-Hakim's (1986) scheme, starting with image enhancement, -segmentation, and feature extraction, however, instead of dedicated hardware, software written with WATFOR, a FORTRAN77 compiler for IBM PC from WATCOM, was used. A general convolution filter routine was written with a changable kernel function. Different kernel sizes are handled with different versions. Minimum filter, (weighted) central-mean low-pass filter, high-pass filter, and several other type of filters are included. A Hough transformation (Ballard, 1981; Gonzalez & Wintz, 1987) for straight line representation is also implemented as an option for feature extraction. This selection is based on the characteristics of both test objects which contain intersections of long lines. The image is transformed into a parameter space consisting of radial distances and polar angles, and then the lines are selected and defined.

For the second approach, a function defined kernel, i.e. the Moravec interest operator (Luhmann & Altrogge, 1986) was implemented.

The third approach is interactive, off-line, and conventional-photogrammetrically flavoured. The images were dumped into a HP ink-jet plotter, and then the hardcopies were digitized on an Altek table digitizer.

THE RESULTS

The first two approaches were found to be very time consuming on the PC/XT. Moreover, due to heavy noise, they failed in most cases. Considerable effort in image enhancement was found to be required. The third approach was therefore utilized for further analysis.

Concerning image enhancement, among all implemented filters, no particular one provided satisfactory results on its own, however a cascading process has shown better enhancement. In all cases studied, only the look-up-table was adjusted, and no filtering was applied.

Table 4 Standard Deviations for Test Object 1 in um

	Digitizing repeatibility	Perspective transformation
Plane 1	59	188
Plane 2	67	188
Plane 3	75	321

In terms of pixel size, a standard deviation of 0.81 pixels was reached; while in terms of relative accuracy, the values are slightly better than 1:1,000.

With the second object, 4 images were taken. A bundle block adjustment with additional parameters was used for the analysis. Because of the relatively poor quality of point defintion, the standard deviations of the measurements are larger. Although by applying a robust estimation technique, these figures can be reduced to less than 0.1 mm, the direct mean values without gross error removal were used. However, in the bundle block adjustment stage, Andrew's sine wave estimator with a tuning constant of 2 is used (Owolabi, 1988).

When analyzed with a bundle block adjustment package with different additional parameter models, it was found that the photo-variant mode provided better results than the block-invariant mode. Three additional parameter models were tested, namely Moniwa's model (Moniwa, 1977); Schut's model (Schut, 1979) which includes 14 polynomial parameters; and Brown's model (Brown, 1976), which has 19 parameters. A third order spherical harmonic model was also tested, however, it did not converge. The RMSE values in three directions at 18 check points are listed in Table 5. The reference is a three photo block of the same object photographed with a 35 mm camera. Moniwa's model is used as the additional parameter set.

Table 5: RMSEs from Bundle Block Adjustment at Check Points
Unit: mm

	X	Y	Z	P
No APs	0.41	0.54	2.16	2.26
Moniwa's Model	0.63	0.58	0.47	0.97
Schut's Model	0.46	0.51	1.15	1.33
Brown's Model	0.38	0.42	0.70	0.90
Reference	0.08	0.10	0.36	0.38

SOME REMARKS OF ON-VIDEO DIGITIZATION

With the plate object, one image was digitized on the image display screen with a software-driven cursor. By processing with a 3-D to 2-D perpsective transformation with full control, the residuals were analyzed as listed in Table 6. A weighted centre of gravity algorithm was applied, with 3x3, 5x5, and 11x11 windows. However, none of these improves the pointing accuracy obtained from the calibration in terms of the standard deviation. This is likely due to the fact that the target shape in this project was not a closed figure, such as a disk or circle. Using the vertex of a parabolic curve which is fitted to the signal amplitudes along two axes improved the accuracy. However, this algorithm has been implemented for taking horizontal and vertical profiles, as well as profiles along two diagonals. The interpolated grey scale, as well as the fitting residuals were used to make selections on both, the observations and the final results. Human interpretation was also applied. This has an effect similar to gross error detection for the video digitization procedure. Because the current system does not allow for a zoom function for image display, this improvement may be insignificant if a zoom function is provided. This is supported by the fact that the standard deviation of the digitized data with gross error corrections has an even smaller value (0.84/0.60 pixels).

The inefficiency of these sub-pixel determination algorithms may mainly be caused by the heavy noise level, as all processed images are originals without image enhancement.

Table 6. The standard deviations of the on-video digitization
Unit: pixel

	direct v.d.	5x5 w.c.g	5x5 parabolic
Sxy	1.1	1.1	0.9
S_0	0.8	0.8	0.7

CONCLUDING REMARKS

The one plane contraint method developed in this study provides an alternative to other methods for rasterstereography, and can also serve as control for other photogrammetric projects. An additional advantage is that the feature extraction work is simplified because of the simplied scene.

It also should be noted that rasterstereography generally takes one camera and one projector. This arrangement does not provide as good a reliability for estimated parameters, as one can expect from conventional photogrammetry. For the self-calibrating case, the image geometry is not strong either. It can be viewed as a 2-station intersection similiar to the case of a stereo-camera.

The ordinary overhead projector as used in this experiment has shown large irregular distortions. This may be caused by its optical configuration and non-metric lenses. However, in the central area of the format, good "metric" quality can be expected. This reminds us the early days of stereophotogrammetry where "only the central part of the image should be used". In the final system, a geometrically better projector would provide a better arrangement, because the geometric configuration of the photogrammetric system would not be strong enough for a sufficient calibration. On the other hand, other models for camera calibration may be used, such as the finite element approach devised by Munji (1986). The magnitude of the distortions of the projector may not be important, however, its stability is.

The potential for obtaining metric properties from digital images on a PC-based image processing system has been shown. An automated fast processing system would be rather difficult to configure without dedicated hardware. About 0.6 pixel accuracy has been obtained for the hardcopy digitization approach. Compared to the 0.14 pixel accuracy reached in Mikhail & Mitchell (1984), this appears to be somewhat inferior. However, the sensor used in this study is a scanning-tube type camcorder. The converted 512x480 pixel image does not have the same quality as the same dimensional images provided by solid-state cameras. For this study, the images were taken under normal working conditions and processed with ink-jet plotter and table digitizer.

With the current configuration, on-video digitization and hardcopy digitization seem to provide reasonable solutions. Although the accuracy of overhead projector and scanning tube camcorder are not good, this combination should still be able to serve for a 1 mm accuracy point determination. However, for an easy use and less numerical problems, a CCD camera as well as a higher quality projector are recommended.

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