DIGITAL IMAGE CORRELATION
ON
THE ANALYTICAL INSTRUMENT KERN DSR11

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ABSTRACT

In the beginning of 1986 an analytical instrument, Kern DSR11, was installed at the Department of Photogrammetry, Royal Institute of Technology, Stockholm. The instrument was delivered with hardware and software for digital image correlation. During 1986 and 1987 a number of projects in digital image correlation have been carried through using the DSR11. This paper contains a summary of those projects and the results obtained.

1. INTRODUCTION

In the beginning of 1986 an analytical instrument, Kern DSR11, was installed at the Department of Photogrammetry, Royal Institute of Technology, Stockholm. The instrument was delivered with hardware and software for digital image correlation. The hardware consists of two solid- state array cameras, analogue to digital converter and frame buffer. The software includes procedures for calibration of the solid-state cameras and application programs for automatic DEM (digital elevation model) and profile measurements.

During 1986 and 1987 a number of projects in digital image correlation have been carried through using the DSR11. This paper contains a summary of those projects and the results obtained.

The application software was tested on set of aerial models used in an ISPRS test conducted by WG III/3 (Li 1987, Torlegård et al. 1984). A second test was conducted after some modifications of the application software. The objective of the second test was to determine the 3-D shape of arbitrary objects using stereo photogrammetry at close-range (Almroth and Hendriks, 1987).

In a third project (Almroth, 1987a, 1987b) the calibration software was evaluated and some changes introduced. After minor changes in the mathematical model used, the method for determining the position of the calibration target in the solid-state sensor array and in the hardware, significant improvements were obtained.

Algorithms for image matching using least squares techniques were developed at the department. A multi-point matching method evolved from this work (Rosenholm, 1986, 1987a,1987b). In a fourth project the multi-point method was implemented and tested using the DSR11.

The objectives of and the results obtained in the projects mentioned above are reviewed in this paper. For detailed information the reader should consult the original papers.

2. DEM TEST

This test was made to study the performance of the Kern correlator in DEM measurements with respect to accuracy and reliability. Comparisons with maesurements by operator and with ground truth were made. The accuracy esimation was made in terms of root-mean- square (RMS) error, bias (mean), maximum error and frequency of blunders. The RMS errors were normalized to the image scale.

The test material chosen from the ISPRS WG III/3 test. In each model a sub aera of about 2500 points is available. The "true" elevation of those points were established by measurements in large scale photography. The models chosen covers different topographic structures from smoth rolling farmland to steep terrain with mountains and forrests.

With operator an average RMS error of 0.15 per mille of the flying height was obtained. The corresponding number when using the correlator was 0.4 per mille. As expexted an ideal image for correlation should have sufficient texture. In addition it should printed with photographic densities in the range from 0.3 to 1.3 in density units. The frequency of blunders were in the range 0 to 16 % depending on the terrain type. The measuements by operator was 1.5 to 4.6 times faster than the maesurements by correlator for the image material used in the test. The test confirmed that the accuracy stated by the manufacturer could be met if the photographs used met the quality specifications.

3. CLOSE-RANGE TEST

The Kern correlator was originally designed for stereo pairs with a base to height ratio of 0.6 and nearly parallel camera axes, e.g. aerial photography. When the correlator is used in close-range applications a number of problems are encountered. The base to height ratio can be unfavourable, the object may not have sufficient texture for the correlator and the surface may be highly reflecting.

In this test the object was texturized by projecting a pattern on it at the time of photography. Relations between pattern size, filmtype, pixel size and the influence of reflections were investigated. Two emulsions, Kodak Tri-x Pan and Kodak Plus X-Pan were used. The pattern used for projection was a

computer generated random pattern, produced with the size of
the elementary cell ranging from 50 to 300 um.

External and internal precision were estimated. The external
precision was computed from a grid of 700 checkpoints on the
object. The check points were measured in a Leitz 3-D
coordinate measuring machine. The internal precison was
estimated from replicated measurements.

In the test no significant difference was found between the two
emulsions used. It was found that reflections could be kept at
a level that did not interfere severly with the correlation.
Matting the surface resulted in an improvement of the accuracy,
but matting may not be permitted in many applications.

The system used for the test has a pixel size of approximately
13 by 16 um. Patterns with an elementary cell size of 150 to
200 um gave optimal results.

More than 90% succesful correlations were obtained. However
the external precision was unsatisfactory and there was a
sytematic trend. The cause of the systematic error was later
found in the hardware. Testing software for automatic
measurement of fiducials, it was found (S.Lutz, Kern Aarau,
personal comunnication) that the automatic gain control of the
solid- state cameras used in the system introduced a shift in
the x direction.

	Gain control	RMS (mm)	Bias (mm)
correlator	on	2.200 - 3.306	-1.605 - -3.088
correlator	off	0.072 - 0.095	0.022 - 0.036
operator	-	0.414 - 0.475	-0.032 - -0.039

Table 1. RMS when compared to the checkpoints. Automatic gain
control of the solid-state cameras on and off. RMS for same
model measured by operator for comparison.

Since this could explain the large RMS values obtained one of
the models was remeasured after turning the gain control off
and introducing improved calibration procedures for the
solid-state cameras. The results obtained show a considerable
improvement compared with the first test. The RMS compared to
ground truth obtained when measuring one model with the
correlator and the automatic gain control turned off and on are
listed in Table 1 as well as the RMS from operator measurement
of the same model.

4. SOLID-STATE SENSOR ARRAY CAMERA CALIBRATION FOR DSR11

The Kern correlator consists of hardware and software. In the preceeding sections some tests of the application software have been reviewed. The hardware and the calibration software for the solid-state sensor array cameras used for digitizing the photographic image was dealt with in a separate project.

In a preliminary investigation (Almroth, 1987a), the existing calibration procedures based on an affine transformation between the coordinate system of the stages of the instrument and the coordinate system of the solid-state cameras, were tested and evaluated. From the results of this test it was decided to expand the mathematical model to include corrections for radial and decentering distortion.

Radial and decentering distortion were found to be significant. The presence of play in the spindles of the stages resulted in a systematic trend in the residuals after calibration. This trend was removed by changing the way of moving the stages during the calibration. The expansion of the mathematical model, the fact that the automatic gain control was turned off and the change in the measuring procedure resulted in a considerable improvement. The standard error of unit weight was reduced from 4 to 1 um. Thus accuracy of the solid-state camera calibration and the accuracy of the grid calibration of the instrument are of the same order.

5. MULTI-POINT IMAGE MATCHING FOR 3-D MEASUREMENTS WITH KERN DSR11

The multi-point matching method is intended for matching in images with the x-direction (the line direction) equal to the epipolar lines. Normal case photographs, with the epipolar lines parallel to the base, are suitable for this purpose. The original photographs are transformed to the normal case by projecting them on a surface with the x-axis parallel to the base. Two types of photograps were used. Convergent photographs of a cardoor with a projected random dot pattern and normal case photographs of rock walls in tunnels.

The investigation was centered on algorithms for practical methods to use the multi-point matching method in the DSR11 and on the effects of low- pass filtering on convergency speed. The effects of the weights of the constraints used and the accuracy and repeatability of the results were also treated.

The method has a high reliability in the center of the parallax grid. The pull-in range is high , but convergency speed is slow. Low-pass filters have a significant improving effect on the convergency speed.

6. DISCUSSION

The performance of the correlator was improved by a minor change in the hardware configuration and by improved calibration procedures. The aerial models used in the DEM test (see section 2) were never remeasured after changing the hardware. Since the base to height ratio is more favourable than in the close-range models used in the other test (see section 3) an improvement can be expected also when measuring DEM's from aerial models. An indication of this is that in the close-range test, the estimated RMS improved considerably after the change in the hardware.

The important part in the soild-state camera calibration is to obtain homogeneous accuracy in solid-state camera and grid calibration. A small pecentage of correlation failures will be present in most cases. Thus the operator has to measure the points where the correlator failed. Mixing operator and correlator measurements we still want to have an equal quality in both types of measurements.

7. CONCLUSIONS

The Kern correlator has been sucessfully applied both to aerial and close-range imagery. The calibration procedures for the solid-state cameras in the system have been improved and a status have been reached were the accuracy of the grid calibration of the instrument and the calibration of the solid-state cameras are of the same order. Further the concept of using image correlation techniques in combination with an analytical instrument for testing and developing algorithms and procedures for digital photogrammetry has proved succesful.

The close range test indicates that it possible not only to automate the measuring procedures but also to improve accuracy by introducing correlations techniques.

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