VIDEO IMAGING FOR CONTROLLING DIFFERENTIAL GPS MEASUREMENTS

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ABSTRACT:

In order to control the accuracy of differential GPS positioning in a low altitude geophysical sounding flight, vertical video images taken from the airplane with a non-metric video camera were used to define the exterior orientation of the camera and the position of the GPS antenna on the plane. A simple precalibration of the camera, based on plane angles, was used. The accuracy of differential GPS using pseudo ranges was ± 6.1 m in the X- and Y- coordinates and ± 4.9 m in the Z-coordinate.

KEY WORDS: Non-metric, Calibration, GPS, Digital Systems.

1. INTRODUCTION

The Geological Survey of Finland performs very low altitude (60 m above the ground) geophysical sounding flights, which requires a continuous 3D definition of the position of the airplane. Until now, the positioning has been made by using a Doppler radar and vertical super-wide angle colour video imaging. To improve the accuracy and to decrease manual work, a test was made to define the feasibility of differential GPS for positioning when using pseudo ranges.

To control the accuracy in real working conditions, a decision was made to perform photogrammetric control measurements. They were based on vertical video images taken from the airplane over a geophysical calibration point surrounded by 16 targeted control points. Photogrammetric bundle block adjustment was used to define the coordinates of the flight path giving the control over the GPS coordinates.

Due to the estimated accuracy of differential GPS positioning (worse than ± 1 m) a built-in low quality video camera was used. A calibration of the camera was necessary anyway.

2. CALIBRATION OF THE CAMERA

2.1 Camera

The video camera which had been used already for several years for positioning, was a Panasonic F10 CCD camera. The image array consisted of a 574 x 581 pixel matrix. The lens was a Molynx objective 1.4/4mm giving a usable angle of view of about 120^g. The geometric quality of the lens was very poor. The maximum radial distortion values were over 50 pixels.

2.2 Calibration method

Due to the low accuracy requirements, a simple test field calibration method was used. It is a modification of the method presented in (Finsterwalder-Hofmann, 1968) and has parallels with goniometer calibrations.

A symmetric horizontal linear group of targets is photographed, so that the horizontal optical axis goes through the center of the group. If the directions to the targets from the projection center are known (measured using a theodolite) and the image coordinates are measured, the direction to the fiducial center (m) in object space can be estimated from the directions of the image coordinates of neighbouring targets (m-1) and (m+1) using linear interpolation:

$$\beta_m = \beta_{m-1} + \frac{(\beta_{m+1} - \beta_{m-1})(x_m - x_{m-1})}{x_{m+1} - x_{m-1}}$$

where

β = horizontal angle
x = image coordinate along the target line

Because the image data is treated using analytical methods, the principal distance (c) can be defined without any optimation. Thus the radial distortion (Δr) at the target (i) can be calculated using the known formula:

$$\Delta r_i = c * \tan(\beta_i - \beta_m) - (x_i - x_m)$$

To calculate the tangential distortion, the rotation of the camera axis must be known. It can be defined calculating the exterior orientation of the camera using the points on the calibration line as control points. Another way is to calculate it iteratively from the asymmetry of the tangential distortion values on diagonals. Thus the tangential distortion (Δt) can be defined using perpendicular components of directions and image coordinates with the approximate formula:

$$\Delta t_i = \frac{c}{\cos\beta} \tan(\delta_i - \delta_m) - (y_i - y_m)$$

where

δ = vertical angle
y = image coordinate perpendicular to the target line

Appropriate functions

$\Delta t = f_t(x)$ and
$\Delta r = f_r(x)$

can be defined to control the quality of the calibration and to facilitate the interpolation of distortion values on the line. They must be defined through the whole diagonal, because the fiducial centre is not the point of best symmetry.

Making the calibration using different rotations of the camera gives distortion values over the whole image.

2.3 Practical realization

A 48 m long horizontal line was targeted with 44 sheets of white paper size A3 on the door of an airplane hall. The door was not a plane (unevenness up to 60 cm), but this had no effect on the calibration results, because the angle measurements and video imaging were made on the same point. Several horizontal video images were taken with 4 different rotations (calibration line parallel to image sides and main diagonals) of the camera. The imaging distance was 16 m meters. One pixel corresponded to 46 mm in the centre of the image.

Horizontal and vertical angle measurements were made with a Wild T2000. For checking purposes also the distances from theodolite to targets were measured.

2.4 Digitizing and coordinate measurements

The video images were digitized using a digitizing system of the Technical Research Centre of Finland. The output image had an image size of 560 x 710 pixels (Fig. 1).

The selected digitized images were measured visually on an InterPro 6280 workstation using Microstation Imager software. The estimated pointing accuracy was ± 0.5 pixels.

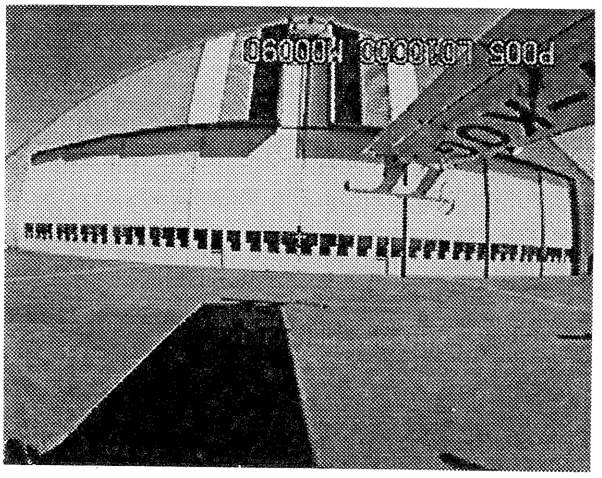

Figure 1. A calibration image. The targets are the rectangles on the lower corners of the windows.

2.5 Calculation of calibrations

The calculation of distortion values was performed using the formulae above and four images with two rotations. The calibration line in all images was approximately parallel to the x- or y-axes.

In Figure 2 are the results of radial calibration. Polynomial curves of 7th degree were fitted to distortion values of two similar images with standard deviations of ± 0.5 pixels. The distortion values on x- and y-axes differ from each other, which can be interpreted as a scale error of the CCD array or of the digitizing system. The scale factor between the axes was 0.97.

The systematic effects of tangential distortion remained below 1 pixel and were discarded.

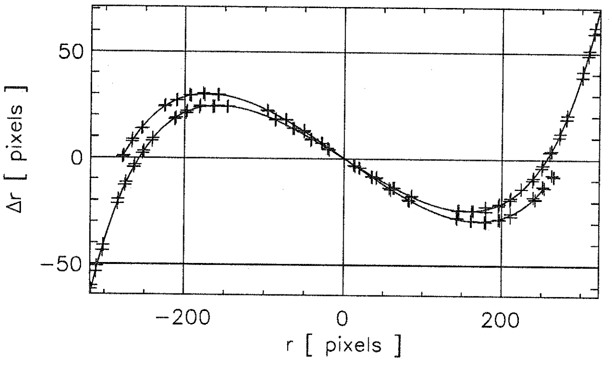

Figure 2. Radial distortion (Δr) of the video camera for the diagonals parallel to x- and y-axes. The crosses mark the distortions for individual definitions. The curves are polynomials of 7th degree fitted to the values.

2.6 Checking the calibration results

The calibration results were checked by calculating the exterior orientation of some images which were taken with calibration images, but with different attitudes. Because the control points were practically on a single line, the system was nearly singular. Due to this, only some orientation parameters could be used for checking. Because the largest calibrated distance was 300 pixels, no points outside this distance were included in the calculations.

The first image was rotated 26^g. Its exterior orientation gave an error of -8 cm for the coordinate in the direction of the calibration line and +5 cm in the distance. The standard error of the adjustment was ± 0.9 pixels.

The second image (Fig. 3) was taken so that only the residuals and the standard error gave valid information. The standard error was now ± 1.1 pixels which proves, that the calibration values are valid also outside the diagonals.

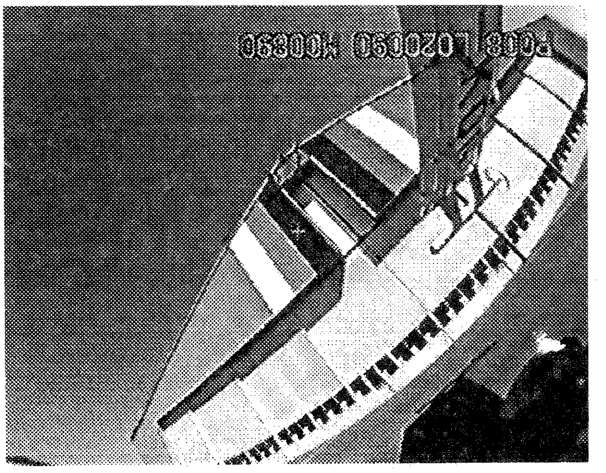

Figure 3. An image used for checking the quality of the calibration.

3. FLIGHT TEST

The test area covered an area of 150 m x 200 m. The evenly distributed 16 control points were targeted using cross targets, the pegs of which were 35 cm x 150 cm. In Finland this type of targets is normally used for 1:16000 aerial photography. The xyz-coordinates of these points were determined using GPS and Wild T2000 theodolite and a DI2000 distance measurement device. The accuracy of these points was estimated to be ± 5 cm.

3.1 Equipment

In the aeroplane there was an Ashtec L-XII GPS receiver collecting data with an interval of 0.5 sec. and a video camera. Two other GPS receivers were on two control points outside the test area. For synchronization of the GPS system and the camera, a manually triggered electronic pulse was sent to both devices when the plane was over the test area. For GPS the pulse was treated as the shutter pulse of a camera, and the time was registered in a GPS file. In the video camera a cross was generated in the image.

3.2 Images

The test area was flown from 8 directions. The camera took images with 50 Hz frequency, but normally from every crossing only 1 - 2 images were selected for further processing. However, in one case a strip of five images was selected to test the internal properties of the imaging system.

The image quality proved to be very poor (Fig. 4). Even in the centre of images the targets were badly deformed and swollen. The forward motion of the plane was 50 m/s leading to a movement of 1 m (= 4 pixels) during an imaging cycle, being the major reason for the bad quality. Huge changes in the radial distortion near the image boarders distorted the cross targets to ellipses.

These images were digitized and measured like the calibration images. Due to the large distortions and poor image quality, points located further than 320 pixels from the image centre were excluded. It was also impossible to select natural tie points for the block adjustment.

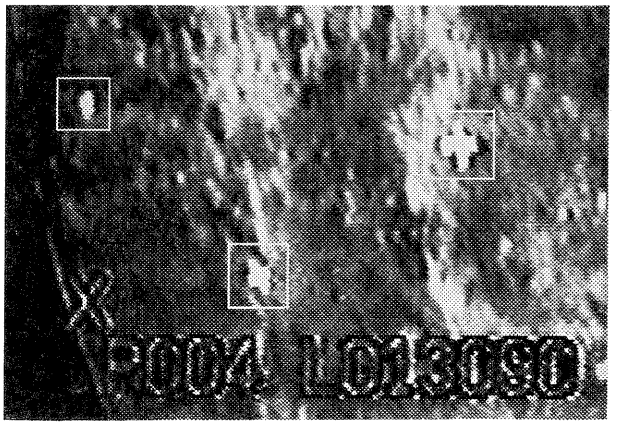

Figure 4. Different shapes of cross targets in a corner of an image.

3.3 Calculation of the exterior orientations

The calculation of the image block was made using the ESPA software (Sarjakoski, 1988), which allows a very general and flexible treatment of different types of observations and the usage of additional parameters for interior orientation. All selected 21 images were included in a single image block. The amount of control points per image was 8.5, but because of multiple overlap, additional parameters were included. The selected model was Ebner's 12 parameter model (Ebner, 1976).

The block adjustment produced a standard error of ± 1.2 pixels. The mean errors of unknown projection centres varied in plane coordinates between ± 0.20 and ± 0.95 m depending on the distribution and the amount of control points in the image. The corresponding values for the height were ± 0.11 and ± 0.53 m.

An idea of the internal precision was obtained by calculating the distances between five images of a strip. The images were taken with an interval of 0.08 seconds corresponding to a distance of 4.36 m, if the speed of the plane has been constant. The standard deviation of the distances was ± 0.14 m, which corresponds to ± 0.6 pixels on the image.

The effect of additional parameters can be seen in Figure 5. In the corners of the image the precalibration has not been very successful. Especially, the corrections to tangential components were large. On the other hand, the amount of points in the corners of the images was quite low, and this can be seen as an extrapolated area in the self calibration. Nevertheless, corrections up to 3 pixels were still necessary on more central areas.

A block adjustment without additional parameters produced a standard error of ± 1.9 pixels, and unknown coordinates correspondingly worse than with additional parameters.

4. COMPARISON WITH GPS COORDINATES

About the GPS measurement itself there will be an other report and only primary information is given in this paper.

For the comparison, the coordinates of the GPS definition had to be interpolated to the time of the selected video imaging using linear interpolation. Because the time of the video imaging could be defined only through the generated cross on the image and the image count, the accuracy is limited by the imaging frequency (50 Hz). The mean error caused by the timing error was thus ± 0.5 m.

For the comparison, only such images were selected, which had a good distribution of control points. Also only one image between two GPS registrations was selected. In the calculations the mean of two GPS definitions was used. Totally seven comparisons were made.

The comparison of the GPS and the photogrammetric positioning gave a standard deviation of ± 6.1 m for planar coordinates and ± 4.9 m for the height. Because the photogrammetric method is much more accurate (better than ± 1 m) the results reflect the accuracy of GPS measurements.

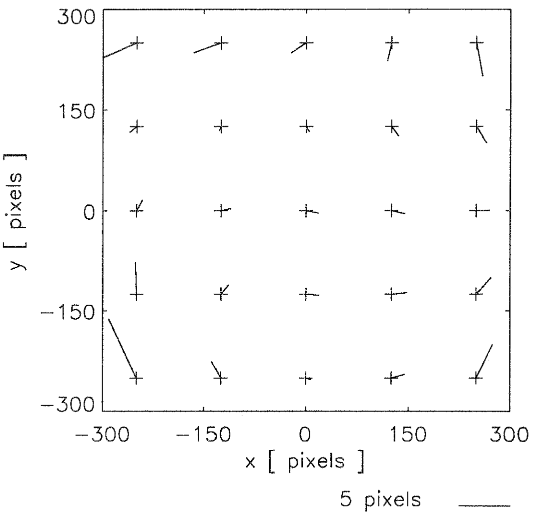

Figure 5. The distortion defined in the block adjustment.

5. CONCLUSIONS

The calibration method used produced the accuracy required; and compared with the maximum radial distortion (> 50 pixels) and the timing error in the flight, the results look rather good. However, if one thinks of the subpixel accuracies achievable using digital images, the results are very modest.

The differential GPS measurements fulfilled the expectations concerning the accuracy and the speed of the positioning.

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