ON-LINE DATA ACQUISITION FOR MULTI-TEMPORAL PHOTOGRAPHY USING THE ANALYTICAL PLOTTER OMI AP-2C

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ABSTRACT

Photogrammetric monitoring of displacements requires repetitive photography with the associated observations. The conventional mensuration scheme of targetted and natural points is characterized by an off-line mode of functions. In an effort to reduce the long delay between data acquisition and presentation of the results and also to improve the overall accuracy, an integrated measuring system was designed and developed using the computer-controlled capabilities of the analytical plotter OMI AP-2C. This on-line mode of operations increases the speed of execution, enhances the quality of data, offers editing capabilities and increases flexibility.

PHOTOGRAMMETRY AND DISPLACEMENTS

Photogrammetry can be used for geometric monitoring of displacements. The entire deformable body is usually represented by a number of properly distributed 'detail' points. The recording of the images of these detail points on photographs taken at different time intervals enables us to determine the motion of these points in the space domain with respect to a stable reference system.

Consequently, measurements must be performed on multi-temporal photographs of the same clearly identified images of the points of interest. We can distinguish two types of detail points: a) targetted (signalized) points, usually for laboratory environments, accessible areas, and high accuracy requirements, and b) natural (physical) points, usually for remote areas, on-site difficulties, lower cost, medium range of accuracies, and monitoring of areas not covered by targets.

CONVENTIONAL MEASUREMENTS FOR NUMERICAL PHOTOGRAMMETRY

The conventional photogrammetric data collection consists of three steps: a) locating (selection and identification), b) marking, and c) measuring of points. It is mainly dictated by the type of photographic images and by the available equipment.

The mensuration of signalized points involves the third step only and is more efficiently performed on a mono- or stereo-comparator. To save time and avoid keypunching errors, the measured information is sent directly to the computer for further processing. However, this remains an open-loop system because the information flow is unidirectional. The missing closed-loop link prevents operations such as: automatic positioning on the photographs at predetermined locations, and on-line editing.

The situation changes drastically when natural points have to be measured. The point transfer operation between photographs taken at different times may prove to be difficult and laborious (e.g. due to changes in perspective). To overcome this critical stage, the mensuration procedure is separated into two operations (Armenakis, 1984). In the first, point location (selection/identification) and marking are performed with a point transfer and marking device, such as the Wild PUG3. To verify that the same points appear on photographs from different epochs, 'pseudo' photo-pairs are formed according to the 'cross-identification' procedure. In the second, the actual measuring of photo-coordinates is performed on a stereo-comparator using the 'real' photo-pairs for each epoch. The preservation of stereoscopic perception in both operations is highly desirable, since it provides better results in locating and measuring of the points of interest. However, there are some shortcomings which reduce the productivity and flexibility as well as the reliability of the observations. Some of these limitations were observed to be: poor stereoscopic perception, manual operations, loss of information, mechanical limitations, lack of film flatness, emulsion deposits, storage and labelling problems, lack of editing capabilities, point misidentification.

SEMI-AUTOMATIC PHOTOGRAMMETRIC MEASUREMENTS WITH THE ANALYTICAL PLOTTER OMI AP-2C

From the previous discussion is obvious, that the practical approach is separated physically and timewise into different phases. That is, an off-line mode governs the mensuration of photo-coordinates of targetted and of natural points. Consequently, an ideal solution would be one which combines all the operations into a closed-loop on-line system. This means an interface to a computer which provides complete control of the operations through computer-controlled measurements. Thus, a computer-assisted comparator would provide on-line data collection and allow for tailoring of the mathematical model to the data flow. It also facilitates direct storage of the output in the computer for editing and processing.

As has been addressed earlier, one of the requirements for the data collection system is the improvement of measuring conditions using three-dimensional observations. Therefore, even when considering a wider field of applications, the instrument which fulfills all these conditions is the analytical plotter. It can be used as a mono/stereo-comparator and as a stereo-plotter. The feed-back between stereo-comparator and computer gives the system unlimited possibilities. Normally the extent of existing software represents the principal restricting factor. Therefore, most of the attention is directed towards the development of a computer-aided data collection system.

Measurements of Targetted Points

Mensuration of discrete targets can be performed in mono-comparator mode. Either the left or the right photo-carriage of the analytical plotter is used for this single image operation because stereoscopic observations are not necessary for targetted points. To take full advantage of the computer-driven carriages, the measuring process is automated to a certain extent by positioning the floating mark near predetermined point locations.

Approximate photo-coordinates are used for this. These are normally obtained in two ways (see also Jacobsen, 1984; Perry, 1984), although a fully automatic system is described in Brown (1984). a) Use of a digitizer. The signalized and reference points (fiducial marks) are digitized from a paper print of the corresponding diapositive. After the reference points have been measured on the analytical plotter, the approximate photo-locations are determined by a 2D-similarity transformation. b) Use of object coordinates. After measuring of at least three image points and performing a space resection, the locations on the photograph are precomputed using the exterior orientation parameters plus the object coordinates.

The predetermined photo-locations are computed within a coordinate system whose origin is the centroid of the reference points, and whose axes are parallel to the measuring axes of the photo-carrier. These coordinates as output from the computer, form the input to the analytical plotter registers which cause the photo-stage to move to the vicinity of the targetted points. Automatic point locating is followed by three steps: fine pointing, recording, and storage of the photo-coordinates. The system provides the options: automatic sequential or operator specified point numbering, capability to revisit a point, change or keep the point identification number, add or delete a point. Up to 110 points per photograph can be measured while photographs from either metric or non metric cameras (automatic or manual driving to the fiducials) can be handled.

Measurements of Natural Points

The point selection/identification phase for natural points has innate possibilities of errors, and measurements on various multi-temporal photographs is a laborious task. The unique characteristics of the analytical plotter are also used for an integrated 'cross-identification' and measuring procedure which ideally combines all the mensuration steps and minimizes errors and operator strain.

The point location using the 'cross-identification' procedure needs to be independent of external reference systems (Armenakis, 1984). The problem is defined as: Given a photograph L1 and a photo-vector of a point at epoch 1, determine the corresponding photo-vector on another photograph R2 at epoch

2. The implied analytical method employs formation of 'real' and 'pseudo' models based on the relative position of photographs at the same or different epochs respectively (Fig. 1). According to this method, the location of the photo-points at various periods is based on a more objective criterion than human perception (which is not excluded). Therefore, the photo-coordinates provide the means for the point location phase. Thus, after locating the points of interest at the preliminary stage of mensuration, their coordinates are stored in the computer. Then, whenever these points are requested, the measuring mark is automatically driven to their location and the immobility of the corresponding photo-stage is ensured. The requirement for a stationary photograph in conjunction with the need of model formation for establishing relative positions of the photographs, leads to the principle of dependent pair analytical relative orientation. The origin of the coordinate system is set to be at the perspective centre of the fixed photograph for both 'pseudo' and 'real' models.

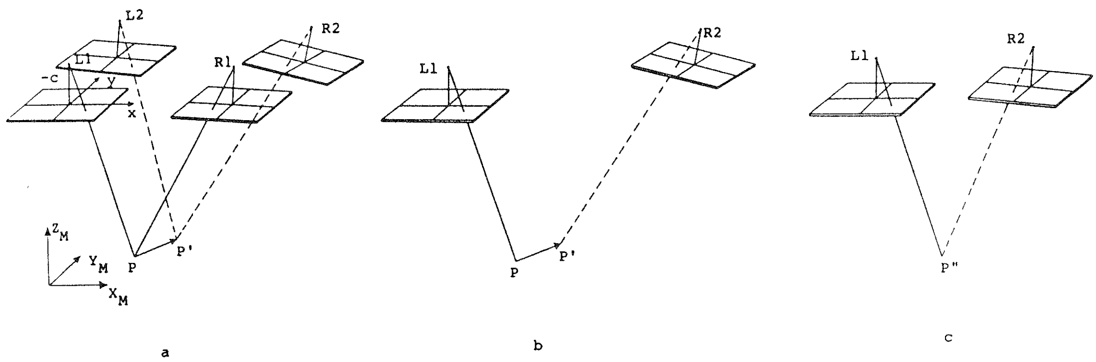

Figure 1: Determination of corresponding photo-points using 'real' and 'pseudo' models.

To ensure that the points exist in both epochs, photographs L1 and R2 are used at the initial stage. Assuming L1 to be the reference photograph, the position and orientation (bx), by2, bz2, OM2, PH2, KP2 of the dependent photograph R2 with respect to the fixed L1 are computed using the coplanarity equations.

Having established an 'approximate' relative orientation of the 'pseudo' model, the operator locates well identified natural detail points on the photographs from the two different epochs. It is expected that residual parallaxes will occur due to two reasons: a) poor geometric intersection of the photographic rays depending on the camera positions and orientations, and b) various magnitudes of displacements at different zones within the overlapping area. These parallaxes are manually removed, and the proper photo-coordinates referred to the fiducial photo-system - not to the carrier photo-system - are stored.

At this initial phase, where both photographs are from different epochs, the stereoscopic perception might need to be improved. This can be achieved by controlling the lateral magnification and rotation of the image. Large KP rotation between two photographs can be eliminated by optical rotation of the images. Differential and simultaneous zoom magnification for both the left and the right photographs are obtained by adjusting the optical train. Although both operations can be computer-controlled (Masry and Faig, 1977) the nature of near vertical aerial photographs does not seem to justiry the additional computations which may overload the computer and thus delay the measuring process.

The formation of the 'pseudo' model between photographs L1 and R2 provides the means for selecting, measuring, and storing the photo-coordinates of the detail points at different epochs. Consequently, their corresponding images at the same epoch will be determined by restituting the 'real' model. Thus, photograph R1 replaces R2 on the right photo-stage and is relatively oriented with respect to the fixed photograph L1. Since the photo-coordinates x_1, y_1 of the stationary photograph are the reference points and can be automaticallly relocated, the goal is to determine the corresponding photo-coordinates on the dependent photograph.

In order to determine the corresponding coordinates x_2, y_2 the proper model coordinates XM, YM, ZM have to be defined since the elements of the interior and exterior orientation of the dependent photograph are known. An additional constraint is that these model coordinates must correspond to the recorded reference photo-coordinates x_1, y_1 since they can be restored automatically through the servo-motors of the stationary carrier. This constraint is materialized by the spatial direction of the original projected ray O_1p_1 (Kratky, 1984) emanating from the fixed photograph, where $x_1, y_1, -c_1$ are the coordinates of photo-point p_1 with the origin of the coordinate system at $O_1(XC_1, YC_1, ZC_1)$ (Fig. 2). The photo-coordinates of the corresponding point p_2 are determined and then recorded by introducing a Z movement, enforcing this constraint by having the servo-motors materializing the initial direction O_1p_1 and stop when perfect stereo-vision is achieved. Therefore, an iterative positioning process is adopted which consists of the following steps:

1. Drive automatically to point p_1 on the reference photograph since its coordinates are known, by setting:

$$XM = x_1, \quad YM = y_1, \quad ZM = -c_1$$

2. Enter new ZM values through the footdisk, so that:

$$ZM_i = ZM_{i-1} + \Delta Z_i$$

3. Extend the ray O_1p_1 along its original direction by calculating new values for XM, YM:

$$sc = ZM_i / -c_i, \quad XM_i = sc \cdot x_i, \quad YM_i = sc \cdot y_i$$

4. Eliminate any remaining local y-parallax, which might exist due to imperfections of relative orientation, by moving the non stationary photograph.

5. Verify whether the correct value of x-parallax has been determined so that the two measuring marks are fused into one floating mark which contacts the virtual model of the object at the correct point.

6. Examine if the conditions of steps 4 and 5 are fulfilled. If yes, then the intersection of ray AO_2 with the image plane of the dependent photograph determines the coordinates x_2, y_2 of point p_2. If not, go to step 2.

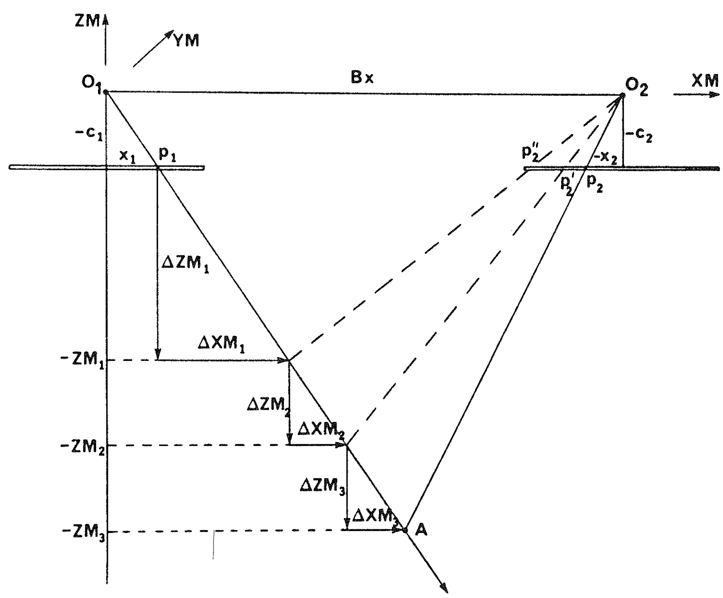

Figure 2: Geometry for the determination of x_2, y_2.

It is obvious that with this iterative positioning procedure the introduced vertical motion ZM does not affect (although it does momentarily) the position of the measuring mark on the reference photograph so that the already selected detail point is not lost.

A similar procedure follows for photographs L2 and R2 (epoch 2). They are now placed on the left and right photo-carriers, respectively. However, this time the procedure works in reverse. The reference (or fixed) photograph is photo R2, set on the right photo-stage.

The stereo-mode data acquisition system transfers and measures up to 40 natural points per model. The initial stage provides options to number (sequentially or by the operator), revisit (using the stored model coordinates and y-offsets), delete, replace a point or change its identification number. It can be also used as on-line stereo-comparator. In the second stage it drives automatically to the selected points on the reference photograph, keeps the measuring mark on them and determines the corresponding points on the dependent photograph under the operator's supervision. The preservation of continuous stereoscopic perception increases the reliability of the observations and eases the operator's task.

EVALUATION OF THE ON-LINE COLLECTED PHOTO-COORDINATES

It was originally planned to examine the quality of the collected photo-coordinates by comparing results from the conventional mensuration scheme which involves the point transfer and marking device Wild PUG3 and the Zeiss stereo-comparator PSK, with the on-line measuring system which employs the analytical plotter OMI AP-2C. However, due to temporary unavailability of the PSK, all measurements were performed on the AP-2C. Two pairs of photographs were measured corresponding to two different time periods. For one of the two epochs (epoch 1) the natural points were marked (pugged) on one of the photographs. This followed the customary steps from previous measurements.

Dependent pair relative orientation was performed for both pairs using a combined least squares adjustment. The assessment of the quality of the collected photo-coordinates was conducted with respect to post adjustment tests and comparisons on the variance factor and on the residuals as well as on the residual parallaxes computed for each model point. The chi-square test was performed on the ratio $\sigma_0^2/\hat{\sigma}_0^2$. For df=10 degrees of freedom and significance level $\alpha = 0.05$, the hypothesis ${}_2H_0$: ${}_2\hat{\sigma}_0^2 = {}_2\sigma_0^2$ was accepted for the pair without any marked points which is a global indication of the appropriateness of the functional and stochastic models. However, the hypothesis, ${}_1H_0$: ${}_1\hat{\sigma}_0^2 = {}_1\sigma_0^2$ was rejected in favour of ${}_1H_A$: ${}_1\hat{\sigma}_0^2 \neq {}_1\sigma_0^2$ for the photo-pair containing marked points. Since it is unlikely that the functional model (coplanarity condition) is incorrect, it can be said that either the weight matrix may be improper, or that there may be outlying observations, or that untreated systematic errors may exist. The former two situations were investigated at the present time while the third was not considered at this stage of data collection.

The poor stereoscopic conditions which were noticed at some of the points of epoch 1 led to the examination of the collected photo-coordinates for possible blunders. The 'data snooping' technique proposed by W. Baarda (1968) was incorporated to test the observations against outliers. This test considers the different precision of the residuals, therefore their cofactor matrix was computed as (Vanicek and Krakiwsky, 1982)

$$Q_{vv} = P^{-1} B^T M (I - A (A^T M A)^{-1} A^T M) B P^{-1}$$

with

$$M = (B P^{-1} B^T)^{-1}$$

The test now consists of comparing the absolue values of standardized residuals with the critical value c. That is, if

$$|w_i| = |v_i| / \sigma_{vi} = |v_i| / (\sigma_o \sqrt{q_{vvi}}) > c$$

then the corresponding observation l_i is suspected to be contaminated by a blunder. For df = 10 degrees of freedom, $\alpha = 0.05$ significance level and $\alpha_o \approx 0.001$ for the one dimensional test of the standardized residuals, the critical value c is $\sqrt{F_{1-\alpha_o\,;\,1,\infty}} = 3.29$ (Kavouras, 1982) or $c = t_{1-\alpha_o,\infty}$. While no point was rejected for epoch 2, two points from epoch 1 were flagged as their absolute standardized residuals ($|w_6| = 6.27$, $|w_9| = 3.66$) exceeded the value of c.

Nevertheless, the weight matrix of the observations for the marked photo-pair was reconsidered as one of the possibilities for the failure of the test on the variance factor. The precision of the observations was assumed to be worse by a factor of two. The computations for epoch 1 were repeated with the new $_1P'$ and this time the test on the variance factor passed at the 0.95 confidence level. Moreover, no point was flagged as containing outlying observations although again point 6 showed the largest $|w|$ and passed marginally ($|w_6| = 3.13<3.29$).

Next the redudancy numbers r_i, which represent the effect of a gross error Δl_i on the residual v_i of the corresponding observation l_i were computed as (Förstner, 1985)

$$r_i = (Q_{vv} \cdot P)_{ii}$$

This served as an indicator of the controllability of the obvservations, of the geometric strength of the configuration of the intersecting rays, and as a check since $\sum r_i = df$. The reduncancy numbers corresponding to the x component of the photo-coordinates had extremely small values ($r_{ix} \approx 0.0$) as expected. On the contrary, the redundancy numbers related to the y observations being in the range of $r_{iy} \approx 0.2\text{-}0.4$ indicate a rather strong geometry. Hence, the y observations are much more controllable as they are related directly to the estimated five parameters of the relative orientation and possible gross errors can be detected (cf. Kratky and El-Hakim, 1983).

Another indicator for assessing the measurements was the vector representing the non-intersection of two corresponding rays at each model point. For both epochs, the model coordinates and their residual parallaxes with their mean and standard deviation were computed. The expected accuracy represented by the mean values was very high (< 1 µm) and their difference was insignificant with respect to the capabilities of the measuring instrument. However, the standard deviation of the residual parallaxes $_1s_{RP}$ was about 2.2 times larger than $_2s_{RP}$. Therefore, it can again be said that the model coordinates of epoch 2 have been estimated more efficiently than the ones from epoch 1.

CONCLUDING REMARKS

The data collection is the most laborious, time-consuming and critical part of any photogrammetric system. To improve this, a semi-automatic system was designed and developed using the computer-controlled capabilities of the analytical plotter OMI AP-2C. The software is in modular form and the entire task is built using overlay techniques. The software is written in PDP FORTRAN 77 (except for the basic real-time program and the drivers which are in PDP ASSEMBLER) and runs on the DEC PDP 11/60 computer. The software for the evaluation of the data is written in VS FORTRAN and runs on UNB's IBM 3081 main frame computer. In summary, the system offers the following:

-- Integration of the point location - (selection/identification), transfer - and measuring phases.
-- On-line computer-control of image positioning including automatic driving of the measuring mark to preselected locations on the photograph.
-- Data filing of the photo and point identification numbers and of photo-coordinates.
-- Editing capabilities such as additions, rejections, remeasurements.

-- Man-machine interaction offering to the operator continuous control and involvement in the measuring process.
-- Higher production rate through reduction of preparatory work and of actual measuring time.
-- Better quality of the collected photo-coordinates and less risk of contamination with blunders.

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