Photogrammetrische Woche 1981
Institut für Photogrammetrie
Schriftenreihe, Heft 8, 1982

EXPERIMENTAL INVESTIGATION ON POINT TRANSFER

M. Sigle, Stuttgart

1. Introduction

1.1. Importance of point transfer

For the connection of images or models in aerial triangulation tie points are used which may be signalized points, artificially marked tie points or natural features. The signalization of tie points is for economical reasons restricted to high precision aerial triangulation and cadastral application. Natural tie points are accurate enough, too, but their application requires great organizational efforts. Therefore, artificially marked tie points are normally and widely used for standard aerial triangulation projects.

On the other hand most of the recent accuracy tests for photogrammetric point determination refer to signalized tie points, as they are directed towards refinement of the mathematical model of aerial triangulation and towards highest possible accuracy. There standard deviations of image coordinates in bundle adjustments with self-calibration in the range of 2 - 3 µm have been reached. By contrast, in practical aerial triangulation with artificially marked tie points the standard deviations of image or of model coordinates usually range between 10 µm and 30 µm or more, the point transfer constituting the major source of error.

1.2. Development of instruments for point transfer

The first applications of artificially marked points date back more than 40 years. Especially in the Netherlands from about 1935 onwards tie points were pricked manually by needles. This procedure was developed for the purpose of spatial aerial triangulation and mapping projects in jungle areas.

The first developments of special instruments for transfer and marking of tie points went along with the spreading application of aerial triangulation with first order stereo plotters between 1955 and 1960. A simple combination consisting of a snap marker and a pointing instrument was constructed by Dongelmans at the ITC in Delft and was later manufactured by Zeiss, Oberkochen. The stereoscopic transfer was done under a conventional mirror stereoscope. Even some years earlier the Wild company presented the point transfer instrument PUG, which was to become the most widely used instrument for more than 2 decades. The marking is produced by a rotating metallic drill. The present instrument (PUG 4) has zoom optics and allows different marking diameters like all instruments described in the following.

When the analytical aerial triangulation gained significance in the late sixties, point transfer and point marking was developed to a standard method. Therefore, other companies presented point transfer instruments, too. Examples are: the Variscale stereo point marking instrument of Bausch and Lomb company, with a heated stamp for marking, the Jena Transmark which uses a laser beam, and the Kern PMG 1 with a rotating sapphire needle.

Only about 10 years later some new instruments for point transfer appeared on the market. In 1978 the Kern company presented the Zoom Point Transfer Instrument PMG 2 and the Comparator Point Marker CPM 1 (Klaver, 1978). The PMG 2 is a conventional instrument with marking by a metallic drill, whilst the CPM 1 is equipped in addition with linear encoders installed at the left image carrier for the purpose of measuring image coordinates of transferred tie points or of other points immediately. Thus it combines the functions of a point transfer instrument and of a monocomparator. In 1979 the Zeiss company presented the Point Transfer Instrument PM 1 (Schwebel, 1979), a new instrument which produces the markings by a heated needle.

Photogrammetrische Woche 1981
Institut für Photogrammetrie
Schriftenreihe, Heft 8, 1982

Those new instruments differ operationally in the solution for the coarse adjustment of the photos. At the Kern instruments the photos are fixed by a vacuum holding device, and the image carriers can be moved over the whole model range. At the Zeiss PM 1 the approximate positioning of the photos is done manually on a large glass surface, whilst the final setting is adjusted by common and separate movements of the image carriers within the limited range of ±15 mm.

The development of those new instruments gave rise to some investigations which will be described below. It was to be checked what precision of point transfer could be reached, and how close aerial triangulation with artificially marked points would approach the results of aerial triangulation with signalized tie points.

2. The experimental investigations

A comparison of signalized and artificially marked tie points was intended by means of controlled aerial triangulation with bundle block adjustment and subsequent analysis of results.

2.1. Test material

The photos originate from a 4-fold photo coverage of the test block Appenweier (Upper Rhine Valley) in 1973 (photo scale 1:7,800, Zeiss RMK A 15/23, 4 single blocks with 60 % forward and 20 % side overlap, test area 9.1 x 10.4 km², s. Ackermann, 1976). For the tests with Zeiss instruments the original negatives of the single block with flight direction west-east (WE) was used, while the block with flight direction east-west (EW) was chosen for the measurements with Kern instruments. In the second case film diapositives were used. Both single blocks consist of 7 strips with 17 photos per strip. In each photo 27 signalized tie points are arranged in groups of 3, near the 9 standard orientation points.

Altogether, the test block contains 105 horizontal and 84 vertical given points which are more or less evenly distributed. Their geodetic accuracy, both horizontal and vertical, is about 1.5 cm. For the actual investigation perimeter control with 24 horizontal control points, at an average distance of 2.5 base lengths, was selected (see fig. 1). 53 vertical control points were chosen which, however, could not be arranged as desired in complete chains. This left 81 horizontal and 31 vertical check points for assessing the absolute accuracy of the adjusted blocks. Up to 2 horizontal and 1 vertical check points had later to be deleted because of gross errors.

2.2. Point transfer methods

In each photo a total of 27 artificial tie points were marked. They also are arranged in groups of 3 near the standard positions. The point transfer was executed by two special methods which can be described and compared with the conventional method as follows.

a) Conventional point transfer method (fig. 2)

The conventional procedure of point transfer can be divided in 2 steps. In step 1 the points along the central line of the photo are marked. The points located in the side overlap areas are transferred stereoscopically and marked in one of the photographs of the adjacent strips. So, each point is marked only once in each strip where it occurs.

The second step, consisting of the point transfer into the preceding and the following photograph within a strip, is done during and by the measurements (without marking), if a stereocomparator or a stereo plotter is used. For monocomparator measurements each tie point must be transferred accordingly into the adjacent photos and marked there. This is usually done together with step 1 in a single operation.

b) Point transfer according to Van den Hout (fig. 3)

For the measurements with the point transfer instrument Zeiss PM 1 a procedure was chosen following a (unpublished) suggestion by Van den Hout. The main point is that marking a point should only be done after transfer, or, transferring an already marked point should be avoided.

The method is suited for subsequent monocomparator measurements and is executed point by point instead of photo by photo. A tie point is first selected and kept by a fixed measuring mark in a central photograph and transferred and marked in all overlapping adjacent photographs. Only then the chosen point will be finally marked in the central photo, too.

The main disadvantage of this method is multiple handling of photographs and consequently an increased organizational effort. Referring to the tie point versions described in 2.3., each photo is to be put into the instrument at least
7 times in case of 9 tie points,
12 times in case of 18 tie points and
17 times in case of 27 tie points per photo.

Against that the conventional method needs to put each photo only twice into the instrument independent of the number of tie points involved.

On the other hand a considerable accuracy advantage is expected, as no previously marked point is picked up once more and transferred into another photo. So, any obstruction of the stereoscopic vision is avoided and an increased transfer accuracy can be supposed. Another feature is, that for each of the 27 image points only one measuring mark setting is necessary, while in the conventional procedure the points of the central line must be set 3 times (side lap area) or twice (photo centre) and the total number of settings increases to 42 in a photo.

c) Point transfer according to Klaver (fig. 4)

For the execution of point transfer and image coordinate measurement in a single operation with the instrument Kern CPM 1, a special transfer procedure is needed. The photo in the left hand image carrier is to be measured completely together with the transfer and marking of its tie points within the strip.

The adopted procedure follows a suggestion by Klaver and is divided into 2 completely separated steps. In step 1 the strip tie points are transferred and marked. But contrary to the conventional method (fig. 2) the respective point in the photo corner is used rather than the point on the central line. In the second step, point transfer within the strip and image coordinate measurement are executed. A transfer to the preceding photo is avoided, as being already completed, and the measurement is possible for the complete left photo without taking it out of the image carrier.

Except for some slight modifications, this point transfer method seems to be the only way to combine point transfer and image coordinate measurement in one procedure. With regard to accuracy it could be a disadvantage that only 6 of the 27 tie points of a photo are independently chosen and directly marked and measured. All other tie points result from a single, double or even triple transfer of already marked points. The number of measuring mark settings for the transfer of 27 tie points per photo amounts to 42 in each photo, which is the same as for the conventional method. Adding the setting of the 9 tie points along the left image side for the measurement of image coordinates, we get a total number of 51 settings for the whole transfer and measuring procedure, apart from fiducial marks, control points and check points.

2.3. Image coordinate measurement and block adjustment

The 27 signalized and the 27 artificially marked tie points of each photo were measured in either block by a monocomparator (apart from the Kern CPM 1). The obtained machine coordinates were transformed to image coordinates by a plane similarity transformation and conventionally corrected for lens distortion, earth curvature and atmospheric refraction.

With such input data bundle block adjustments were computed, making use of the computer program PAT-B (Klein, 1978). For all sets of data (signalized and artificially marked tie points) the same control points as described in 2.1. were used. The geodetic control coordinates (x, y and z) were introduced into the adjustment as observations with a standard deviation of 1.5 cm. The weight unit referred to the image coordinates of tie points, control points and check points with an assumed standard deviation of 5 µm. The terrain coordinates of the check points were given weight 0. Thus they have no influence on the adjustment whilst the program is able to print out the residuals and the root mean square values μ_x, μ_y and μ_z as estimates for the absolute accuracy of the adjusted block.

For checking the effects of systematic errors on the adjustment results, all computations were executed with and without self-calibration, for which only one set of 12 blockinvariant additional parameters was chosen. The regular distribution of the tie points near the 9 standard positions in the photographs was expected to compensate the major systematic image errors almost completely, as far as they are constant throughout the whole block.

Additionally, the influence of the strength of the image ties on the accuracy of the block adjustment should be examined. Therefore 3 different versions were computed using 1, 2 or all 3 points of each triplet of tie points, giving blocks with 9, 18 or 27 tie points per photo.

For each version the block adjustment gives an estimation of the standard deviation σ_0. The error contributions of point transfer and point marking to those σ_0 values are of special interest for our investigations. They can be estimated by a variance analysis from the σ_0 values of the various cases (signalized points versus artificially marked points and adjustment with versus without additional parameters).

3. Investigation with Zeiss equipment

The measurements with Zeiss instruments were executed in Oberkochen (December, 1979) by R. Bettin from the Photogrammetric Institute of Stuttgart University. Preliminary results were published at the occasion of the ISP congress 1980 (Ackermann, Bettin, 1980). After final data reduction and data clearing the data have been reprocessed. The final results are presented below.

3.1. Point transfer and point marking with the PM 1

The marking of the 27 tie points per photo was done according to the Van den Hout method (see 2.3.) with a prototype of the PM 1. Because this prototype did not allow switching from pseudoscopic to stereoscopic viewing, the point transfer had to be carried out partly with pseudoscopic viewing. The heated needle gave marks of 70 µm diameter of excellent quality.

Altogether 3159 image points were marked. The total operation required $45^h 11^m$ including only the net operation time with the PM 1, excluding the time for the general preparation of the paper prints. Splitting the total time gives 51 seconds for transfer and marking per image point and 22.8 minutes per photo (with 27 tie points).

3.2. Measurement of image coordinates with the monocomparator PK 1

For measuring the image coordinates,the monocomparator Zeiss PK 1 (Schwebel, 1976) was used. During the measurements the recorded data were controlled by the data acquisition program system PK 1-AS which included relative orientation for each model and preliminary strip adjustment with independent models. The block was measured twice, first for signalized points only and thereafter independently for the artificially marked points. This means that fiducial marks, (signalized) control points and check points were measured in either set. Within each data set there were no double measurements.

The time for the measurement of the complete block with signalized tie points amounted to $44^h 02^m$. If we take the 476 fiducial marks and the 300 image points of control points and check points as additional image points into account, the data set consists of 3935 measured image points. Thus the monocomparator measurement took

40 seconds per image point and
22.2 minutes per photo (with 33.1 points average).

The data set referring to the artificially marked points consists of 3863 image points altogether. The total measuring time amounts to

37 seconds per image point and
20.0 minutes per photo (with 32.5 points average).

3.3. Discussion of the accuracy results

The accuracy results expressed in terms of σ_0, r.m.s. values μ and maximum values ε of residuals at check points are put together in table 2, for all versions described in 2.4. The following comments may be given:

a) σ_0 values

With signalized tie points the σ_0 values range between 3.2 µm and 4.0 µm without self-calibration and between 2.5 µm and 3.0 µm with self-calibration. It remains to be explained why the σ_0 values increase consistently with decreasing strength of ties.
The block with artificially marked tie points gives σ_0 values between 7.2 µm and 7.5 µm without additional parameters and between 6.0 µm and 6.1 µm with additional parameters. Again the larger values go together with weak ties.

Those accuracy results can be split in different error components by a variance analysis. Here, the random and the systematic contributions of point transfer and point marking to the total error (standard deviation) of 6.5 µm for point transfer (referring to 18 points/photo). It can be decomposed in a random component of 5.4 µm (also including local systematic errors) and a blockinvariant systematic component of 3.6 µm.

b) Absolute accuracy (μ)

With signalized tie points the absolute horizontal accuracy of the adjusted block ranges between 4.6 µm and 5.3 µm without self-calibration and between 4.4 µm and 4.7 µm with self-calibration. The ratios $\mu_{x,y}/\sigma_0$ amount to 1.4 and 1.7, respectively. The absolute vertical accuracy ranges between 12.3 µm and 12.7 µm ($\hat{=}$ 0.08 $^0/_{00}$ h_g) without additional parameters and between 10.0 µm and 10.5 µm ($\hat{=}$ 0.07 $^0/_{00}$ h_g) with additional parameters. The accuracy improvement by additional parameters is larger for the height (factor 1.22) than for planimetry (factor 1.09).

Using artificially marked points the absolute horizontal accuracy, between 8.1 µm and 8.8 µm without self-calibration and between 6.4 µm and 7.0 µm with self-calibration, corresponds to ratios $\mu_{x,y}/\sigma_0$ of only 1.15 and 1.10, respectively. The absolute vertical accuracy lies between 15.0 µm and 16.5 µm with self-calibration. For the evaluation of such results it should be kept in mind that the distribution of vertical control was irregular and did not meet standard specifications.

4. Investigation with Kern equipment

At the beginning of 1980, the measurements with the Kern instruments CPM 1, PMG 2 and MK 2 were executed in Aarau, also by R. Bettin. The measurements refer to a different single block (flight direction east-west) of the Appenweier test area. And diapositives instead of original negatives were used. Preliminary results have been communicated (Klaver, 1980) at the ISP congress 1980.

4.1. Point transfer and image coordinate measurement with CPM 1

With a prototype of the comparator point marker Kern CPM 1 the measurement of image coordinates for the signalized points as well as the point transfer and the image coordinate measurement for the artificially marked points have been executed in a joint operation. For point transfer the method suggested by Klaver (see 2.3.) was used. The chosen drill with a diameter of 60 µm produced excellent markings.

Altogether 7094 image points were measured. Amongst them are 3159 signalized tie points, 3159 marked tie points, 476 fiducial marks and 300 control points or check points. Recorded measuring times exist for the following parts of the total operation:

- preparation of the 119 paper prints	6^h55^m
- transfer and marking of 684 strip tie points	13^h25^m
- point transfer within the strips and measurement of all 7094 image points	116^h00^m

Thus 3^m30^s per photo were necessary for the general preparation. The transfer and marking of the strip ties required 1^m10^s per point.

For the common execution of point transfer and image coordinate measurement only the total time of 129^h25^m was recorded. A subdivision may be done on the basis of 2 assumptions:

1. The time requirement for mono-measurement of a signalized point, a fiducial mark or a marked point that is not transferred to the following photo of the strip is considered to be the same as with a monocomparator (38 seconds per point for Kern MK 2).
2. The measurement of marked points that are transferred to the next photo within the strip in a joint operation requires, in addition to the transfer, only the setting of the point number and the recording, which can be assumed to take not more than 15 seconds.

Subtracting the time for measuring the signalized tie points 96^h15^m remain for the block with artificially marked tie points. This can further be subdivided in 48^m30^s for point transfer and measurement per photo and in 1^m40^s for point transfer and measurement per image point. About 1^m20^s of that time are needed for point transfer and marking of the image point.

The accuracy results obtained with the prototype of the CPM 1 have not been completely satisfactory (see 4.4.). Therefore, the instrument was modified and the measurements were repeated later with a serial instrument for the north-west corner of the block (4 strips with 5 photos per strip). However, only 15 signalized and 15 artificially marked tie points per photo were measured. They are arranged in pairs of points in the side lap areas and as single points near the nadir points. With 7 horizontal control points near the block perimeter and 9 vertical control points a control version was chosen that approximately corresponds to the previous control in the complete block. Some results are shown under 4.4.

4.2. Point transfer and image coordinate measurement with PMG 2 and MK 2

Contrary to the CPM 1, the marking and the measurement of image points is carried out separately with the instrument combination PMG 2/MK 2. The point transfer instrument PMG 2 is identical with the instrument CPM 1 apart from absent linear encoders. Therefore, the point transfer was not executed again, but the markings produced with the CPM 1 were remeasured with the monocomparator Kern MK 2.

The measuring time with the MK 2 was 74^h25^m for the 7094 image points of the whole block or 38 seconds per image point. Adding the time for point transfer with the CPM 1 (1^m20^s) to this value, we get a total time of about 2 minutes for the transfer, marking and measuring of a tie point with PMG 2 and MK 2. This is about 20 % higher than for the common point transfer and measurement with CPM 1 (1^m40^s).

4.3. Comparator calibration

In view of potentally reducing costs, it is the philosophy of the Kern company to allow consciously some systematic instrumental errors in measuring equipment for image coordinates. Such systematic errors shall be assessed by a comparator calibration and corrected numerically during data processing. For that purpose grid plate measurements are necessary occasionally. From the residuals against the calibrated grid coordinates corrections Δx and Δy for any image point can be interpolated. For the investigation reported here, corrections were interpolated with polynomials of 3rd degree by a Kern computer program.

The efficiency of this calibration was tested for the small block measured with the serial CPM 1. All versions of the block adjustment described in 2.4. were computed with and without an a priori blockinvariant correction of image coordinates, as derived from the grid calibration of the instrument.

4.4. Discussion of the accuracy results

4.4.1. Results relating to the CPM 1 (see tab. 1 and 3)

a) σ_0 values

For the CPM 1 prototype the σ_0 values of the block adjustment with signalized tie points range between 9.0 µm and 12.3 µm without additional parameters and between 4.7 µm and 5.5 µm with additional parameters. As expected, the measurements include rather big blockinvariant systematic errors (about 9 µm) caused essentially by the instrument.
The σ_0 values for the artificially marked tie points lie between 9.8 µm and 12.2 µm without self-calibration and between 6.6 µm and 7.3 µm with self-calibration. This implies a random error of point marking of less than 5 µm.

The standard errors σ_0 for the small block (see 4.1.) remeasured with a serial instrument of the CPM 1 are put together in table 1.

	without comparator calibration		with comparator calibration	
	without additional parameters	with additional parameters	without additional parameters	with additional parameters
signalized tie points	6.8	4.3	4.7	4.2
marked tie points	7.2	5.4	5.6	5.2

Table 1: Standard error σ_0 in µm
instrument: Kern CPM 1 (serial instrument)
sub-block of 20 photos, 15 tie points per photo

σ_0 values of 6.8 µm without self-calibration and 4.3 µm with self-calibration for signalized tie points indicate a significant improvement against the prototype, although a systematic component of 5.3 µm remains, which is due to instrumental errors and image deformations.
With 7.2 µm and 5.4 µm the σ_0 values for the marked tie points are only slightly larger than for signalized points.

The comparator calibration by grid plate measurements has turned out to be a very efficient method for the correction of systematic measuring errors. After correction, σ_0 values of 4.7 µm for signalized points and of 5.6 µm for marked points are obtained. Those values are close to the values reached with additional parameters in the block adjustment. Applying additional parameters after the comparator calibration results only in a marginal additional improvement.

b) Absolute accuracy (μ)

Here, the absolute accuracy is presented only for the original block measured with the CPM 1 prototype. Because of the small number of only 10 horizontal and vertical control points in the 20 photos measured with the serial instrument, the results are not sufficiently significant to be shown here.

With signalized tie points the absolute horizontal accuracy of the adjusted block, as obtained from the check points, ranges between 37.4 µm and 43.6 µm. This clearly displays the effects of the quite considerable systematic instrumental errors of the CPM 1 prototype. Accordingly, the application of additional parameters succeeded to reduce the systematic errors very effectively, giving $\mu_{x,y}$ values between 9.6 µm and 9.8 µm. The absolute vertical accuracy is also very considerably improved by the self-calibration from 0.23 $^o/_{oo}$ h_g to 0.12 $^o/_{oo}$ h_g.

For the block adjustment with artificially marked tie points the absolute horizontal accuracy ranges between 29.0 µm and 38.5 µm without additional parameters, which is mainly explained by the instrumental errors of the CPM 1 prototype. Again the adjustment with additional parameters gave great improvement with accuracy values of 12.0 µm and 12.1 µm. For the height the accuracy improved from 0.24 $^o/_{oo}$ h_g to 0.15 $^o/_{oo}$ h_g by the self-calibration.

4.4.2. Results for the combination PMG 2/MK 2 (see tab. 4)

a) σ_0 values

For the signalized tie points the σ_0 values range between 4.7 µm and 5.7 µm without self-calibration and between 3.7 µm and 4.2 µm with self-calibration. Smaller systematic errors of the comparator give smaller values than for the CPM 1 measurements.
The σ_0 values between 7.1 µm and 7.7 µm without self-calibration and between 6.5 µm and 6.7 µm with self-calibration for the marked tie points include a random point transfer error of 5.2 µm.

b) Absolute accuracy (µ)

As expected, the absolute horizontal accuracy for signalized and marked tie points is better than with the CPM 1 prototype. The results are near 13 µm and 16 µm without additional parameters and near 8.5 µm and 11 µm with additional parameters. Strangely, rather large ratios $\mu_{x,y}/\sigma_0$ between 2.0 and 2.9 without self-calibration and between 1.6 and 2.3 with self-calibration are obtained, obviously caused by remaining block deformations. For the absolute vertical accuracy the self-calibration gave some improvement (factor 1.2), which brought down the μ_z values from 0.12 $^o/_{oo}$ h_g with signalized and 0.13 $^o/_{oo}$ h_g with artificially marked tie points to 0.10 $^o/_{oo}$ h_g and 0.11 $^o/_{oo}$ h_g, respectively.

Summing up the investigation with the Kern instruments, it has been confirmed that the measured coordinates include some systematic instrumental errors, as expected. However, they are effectively reduced or eliminated by additional parameters or by a comparator calibration.

5. Some conclusions

The test results confirm that the analytical aerial triangulation using artificially marked points does not completely reach the accuracy obtained with signalized tie points. However, it is a highly important result that after self-calibration excellent σ_0 values of 6 - 7 µm are obtained with artificially marked tie points, bringing also that case on a quality level referred to a precision aerial triangulation.

The contribution of the actual point transfer to such σ_0 values amounts to about 5 - 6 µm. For the investigated point transfer instruments Zeiss PM 1 and Kern PMG 2 (resp. CPM 1) no significant accuracy differences could be recognized.

A comparison of the 3 tie point versions with 9, 18 and 27 tie points per photo shows the best σ_0 values for the 27 point version, while the best absolute accuracy was mostly obtained with 9 tie points. An explanation may be that the effects of systematic errors on groups of tie points give small σ_0 values for strong ties, whilst the counterbalancing effects of the strength of ties in connection with systematic errors leave larger absolute errors.

As to the comparison of the accuracy results related to the different instruments, it must be clearly stated that the results are not strictly comparable and do not directly reflect instrument quality. The different investigations with Zeiss and Kern equipment refer to two different blocks of the Appenweier test material. Also, the photographic material was different (film negatives against film diapositives) and different point transfer methods were applied. Finally, prototype instruments were used in either case, the observed shortcomings of which have led to improved serial instruments in the meantime.

The results obtained here may be compared with other investigations carried out elsewhere. Reference is made here in particular to tests on point transfer with the point transfer instrument Wild PUG 4, where a part of the Oberschwaben test material was used (Parsic, 1978 and 1980). Measurements of model coordinates with the precision stereo plotter Wild A 10 gave results of a somewhat lower accuracy than presented here, whilst the results of image coordinate measurements with the stereocomparator Wild StK 1 are about equivalent with the results obtained here.

The total times of $1^m 28^s$ (PM 1/PK 1), $1^m 40^s$(PM 1) and 2^m (PMG 2/MK 2) for transfer, marking and measuring of an image point with different point transfer methods demonstrate the high operational efficiency of aerial triangulation with artificially marked tie points. The relative differences cannot be explained by operational differences related with the point transfer instruments. Hence, the reduced number of 27 point settings per photo against 42 with Klaver's method seems to be responsible for the observed time advantage of Van den Hout's method of point transfer, in spite of its organizational handicap because of the required multiple handling of the photographs. It should also be kept in mind that the indicated times refer to tie points arranged in groups of 3 points. Therefore some caution is to be observed when the time requirements for handling double or single tie points are estimated.

The investigations described here are integral empirical tests. They give the primarily wanted information about the total performance of the systems and allow analysis of some of the dominating features. However, all further details about the influence of project parameters, such as image contrast and texture, terrain, photo scale, point transfer method, transfer within and across strips, etc., need further separate investigation.

6. Further trends of point transfer

During the last years the development of photogrammetric instruments and methods was highly influenced by computers and numerical methods. In contrast, point transfer of tie points in aerial triangulation still works almost exclusively with mechanical and optical means. However, it can be supposed that computer aided methods are going to influence point transfer. Two of such methods are briefly touched upon at the end of this report.

6.1. Point transfer with analytical plotters

Point transfer without point marking is technically possible by using analytical plotters (Keune, 1976). It is already applied in practice to some extent.

The simple principle is that any image point is defined and can be reset recording its image coordinates. Thus, in an analytical plotter, after restoration of the interior orientation, the floating mark can always be driven to the image point in question, although the point is not marked in the photograph. It is only the marking of points which is replaced by the recording of image coordinates, whilst for the stereoscopic transfer any suitable method (conventional or according to Klaver, see 2.2.) may be used, although the multiple handling of photographs should be kept a minimum.

The absence of markings permits undistributed stereoscopy. Thus the method has advantageous features. The only point of debate is that a very expensive instrument is used for point transfer.

6.2. Automatic point transfer by means of digital or electronic image correlation

Presently, in the Photogrammetric Institute of Stuttgart University possibilities of using the digital image processing for point transfer are being investigated.

After microdensitometer scanning of small homologous image areas the grey value matrices are digitally matched by correlation techniques. Thus, via recorded image coordinates and with reference to the fiducial marks, point transfer is executed. The method applies, by the way, also to electronic image correlation for which the techniques are known and to some extent available.

The preliminary results indicate that the accuracy potential of the method is extremely high. Transfer accuracies in the order of 1 µm can be reached. With good texture the theoretical transfer accuracy reaches 1 % of (linear) pixel size.

The specialized hardware and software has not yet been developed. But it is expected that with the further automation of photogrammetric processes the digital point transfer by image correlation will eventually replace all other point transfer techniques.

References

Ackermann, F. — Photogrammetrische Netzverdichtung - Das Projekt Appenweier, Schriftenreihe Institut für Photogrammetrie, Heft 1, S. 95-112, Stuttgart 1976.

Ackermann, F., Bettin, R. — An Empirical Accuracy Test on Point Transfer in Aerial Triangulation, presented paper, ISP Comm. III, Vol. 9, Hamburg 1980.

Keune, E. — Point Transfer with the Analytical Plotter AP/C-3, presented paper, ISP Comm. II, Helsinki 1976.

Klaver, J. — Two new Instruments from Kern: The PMG 2 Zoom Point Transfer Instrument, the CPM 1 Comparator Point Marker, presented paper, 44th ASP-ACSM Annual Meeting, Washington 1978.

Klaver, J. — Practical Experiences with the Kern PMG 2 Zoom Point Transfer Instrument and the Kern CPM 1 Comparator Point Marker, presented paper, ISP Comm. II, Vol. 9, Hamburg 1980.

Klein, H. — New Results of Bundle Block Adjustment with Additional Parameters, proceedings of 37th Photogrammetric Week, Stuttgart 1979.

Parsic, Z. — Untersuchungen über den Einfluß signalisierter und künstlicher Verknüpfungspunkte auf die Genauigkeit einer Blocktriangulation, Vermessung, Photogrammetrie, Kulturtechnik, 76. Jahrgang.

Parsic, Z. — Ergebnisse einer Bündelblockausgleichung ohne zusätzliche Parameter mit signalisierten und künstlichen Verknüpfungspunkten, presented paper, ISP Comm. III, Vol. 3, Hamburg 1980.

Schwebel, R. — The new PK 1 Precision Comparator, presented paper, ISP Comm. II, Helsinki 1976.

Schwebel, R. — PM 1 Point Transfer Instrument, a new Module in the Zeiss System for Analytical Photogrammetry, proceedings of 37th Photogrammetric Week, Stuttgart 1979.

additional parameters	No. of tie points per photo	σ_0 |µm|	absolute accuracy μ_x |µm|	μ_y |µm|	$\mu_{x,y}$ |µm|	μ_z |µm|	μ_z |$^o/_{oo}h_g$|	maximal errors ε_x |µm|	ε_y |µm|	ε_z |µm|
signalized tie points										
---	27	3.2	5.2	5.4	5.3	12.7	0.08	15.5	13.3	29.2
	18	3.4	5.0	5.1	5.1	12.6	0.08	13.8	11.3	29.9
	9	4.0	4.8	4.4	4.6	12.3	0.08	14.3	12.0	24.6
12 block-invariant parameters	27	2.5	4.3	5.0	4.7	10.3	0.07	10.5	13.6	26.6
	18	2.6	4.2	5.0	4.6	10.0	0.07	10.6	12.1	26.6
	9	3.0	4.0	4.8	4.4	10.5	0.07	11.6	13.0	23.5
artificially marked tie points										
---	27	7.2	7.5	8.7	8.1	19.9	0.13	25.2	19.7	40.0
	18	7.3	8.3	8.4	8.4	20.7	0.14	32.4	22.2	42.2
	9	7.5	8.1	9.5	8.8	27.2	0.18	27.2	29.5	50.5
12 block-invariant parameters	27	6.0	6.7	6.0	6.4	15.0	0.10	17.4	16.2	32.8
	18	6.0	6.6	6.6	6.6	16.5	0.11	19.9	17.4	34.8
	9	6.1	6.1	7.8	7.0	16.0	0.10	19.0	22.6	38.0

Table 2: Results of bundle block adjustment - Appenweier block WE
(wide angle, photo scale 1:7,800, p = 60 %, q = 20 %)
24 horizontal control points, perimeter, 53 vertical control points
79 horizontal check points, 31 vertical check points
Instruments: Zeiss PM 1, Zeiss PK 1

additional parameters	No. of tie points per photo	σ_0 |µm|	absolute accuracy μ_x |µm|	μ_y |µm|	$\mu_{x,y}$ |µm|	μ_z |µm|	μ_z |$^o/_{oo}h_g$|	maximal errors ε_x |µm|	ε_y |µm|	ε_z |µm|
signalized tie points										
---	27	9.0	46.8	40.1	43.6	36.9	0.24	117.3	120.3	97.2
	18	10.1	44.4	36.8	40.8	35.1	0.23	115.7	115.9	89.0
	9	12.3	41.1	33.2	37.4	34.2	0.22	114.6	114.6	79.0
12 block-invariant parameters	27	4.7	9.8	9.7	9.8	18.5	0.12	23.1	31.6	39.6
	18	4.9	9.6	9.6	9.6	18.0	0.12	23.1	31.5	40.4
	9	5.5	10.0	9.1	9.6	18.3	0.12	25.6	29.9	45.3
artificially marked tie points										
---	27	9.8	38.3	38.7	38.5	34.8	0.23	78.4	101.2	78.1
	18	10.6	35.8	34.5	35.2	34.8	0.23	74.4	90.0	84.1
	9	12.2	30.7	27.2	29.0	38.2	0.25	69.5	74.8	91.6
12 block-invariant parameters	27	6.6	12.9	11.2	12.1	22.4	0.15	27.1	35.2	64.4
	18	6.8	12.9	11.3	12.1	21.1	0.14	25.6	35.2	61.4
	9	7.3	12.4	11.6	12.0	22.6	0.15	28.4	36.8	59.5

Table 3: Results of bundle block adjustment - Appenweier, block EW
(wide angle, photo scale 1:7,800, p = 60 %, q = 20 %)
24 horizontal control points, perimeter, 53 vertical control points
79 horizontal check points, 30 vertical check points
Instrument: Kern CPM 1 (prototype)

additional parameters	No. of tie points per photo	σ_0 |µm|	absolute accuracy μ_x |µm|	μ_y |µm|	$\mu_{x,y}$ |µm|	μ_z |µm|	μ_z |$^o/_{oo}h_g$|	maximal errors ε_x |µm|	ε_y |µm|	ε_z |µm|
signalized tie points										
---	27	4.7	14.2	13.0	13.6	19.2	0.13	35.3	32.7	33.7
	18	5.0	13.9	12.3	13.1	18.8	0.12	34.1	31.7	35.5
	9	5.7	13.7	10.8	12.3	19.0	0.12	34.1	33.9	41.7
12 block-invariant parameters	27	3.7	9.9	7.2	8.7	14.9	0.10	27.4	21.1	33.9
	18	3.9	9.8	7.0	8.5	14.9	0.10	27.9	20.8	34.8
	9	4.2	9.9	6.7	8.5	15.5	0.10	27.9	22.0	37.7
artificially marked tie points										
---	27	7.1	20.9	12.3	17.1	18.3	0.12	50.3	31.2	35.2
	18	7.2	19.6	12.1	16.3	19.8	0.13	47.7	30.5	40.4
	9	7.7	18.9	10.9	15.4	20.5	0.13	48.9	30.4	41.4
12 block-invariant parameters	27	6.5	13.8	8.7	11.5	16.7	0.11	30.5	25.6	48.1
	18	6.6	13.3	9.0	11.4	17.3	0.11	29.0	25.5	45.9
	9	6.7	12.1	8.7	10.5	19.2	0.13	31.1	23.9	50.6

Table 4: Results of bundle block adjustment - Appenweier, block EW
(wide angle, photo scale 1:7,800, p = 60 %, q = 20 %)
24 horizontal control points, perimeter, 53 vertical control points
81 horizontal check points, 30 vertical check points
Instruments: Kern PMG 2, Kern MK 2

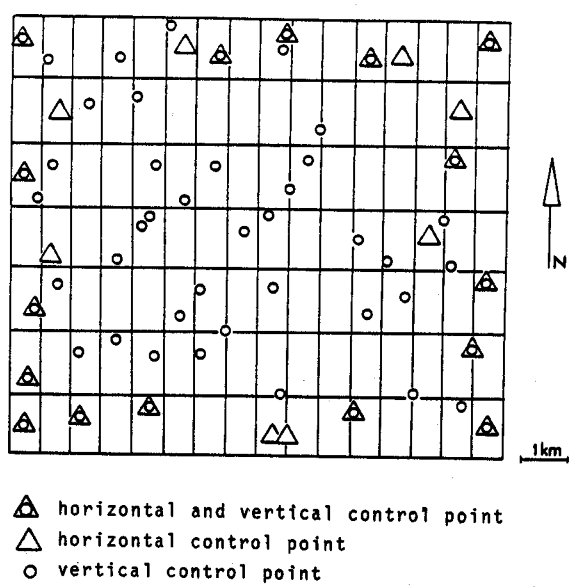
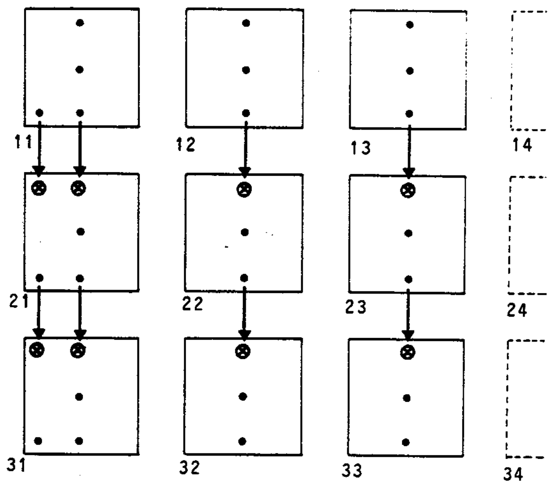


Fig. 1: TEST BLOCK APPENWEIER
Distribution of control points

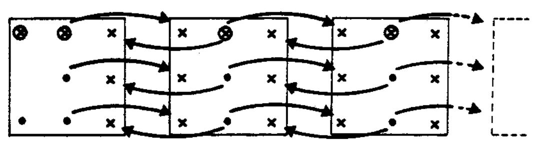
strip 1

strip 2

strip 3



Step 1: Transfer of tie points between strips
Marking of the central column of points



Step 2: Point transfer within a strip

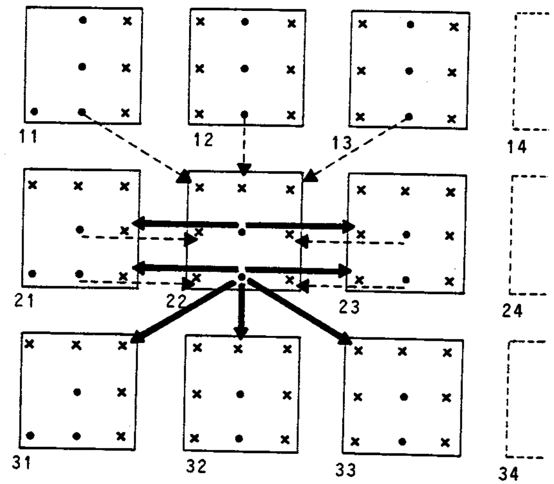
- • image points marked directly and independently
- ⊗ point transferred from the previous strip
- × point transferred within the strip

Fig. 2: Conventional method of point transfer

strip 1

strip 2

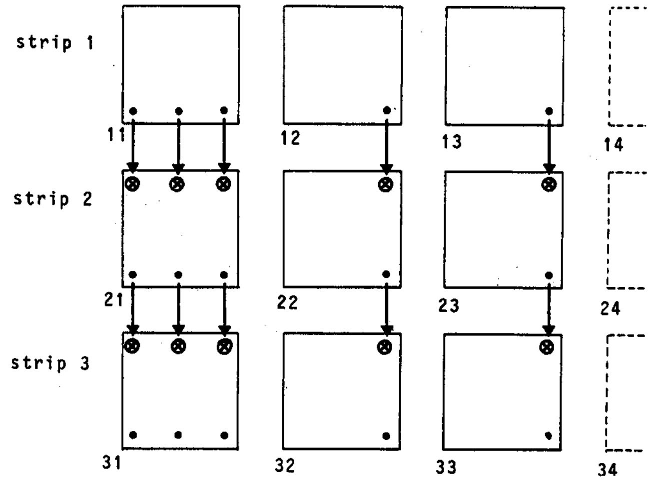
strip 3



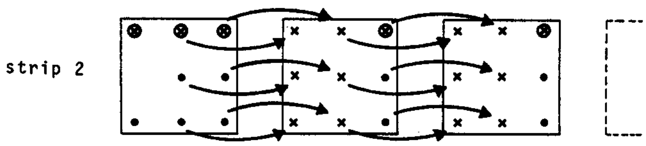
- • point independently selected and kept fixed within a photo, to be transferred into all adjacent photographs before being marked itself
- × point transferred from an adjacent photo

Fig. 3: Point transfer method according to Van den Hout

Photogrammetrische Woche 1981
Institut für Photogrammetrie
Schriftenreihe, Heft 8, 1982



Step 1: transfer and marking of tie points connecting strips



Step 2: point transfer within a strip

- • image point marked directly in the photo
- ⊗ point transferred from the previous strip
- × point transferred within the strip

Fig. 4: Point transfer method according to Klaver for the Kern CPM 1 instrument

Abstract

The great importance of point transfer in practical photogrammetry has resulted in the past years in the development of some new instruments which are intended to increase accuracy and cost effectiveness. For this reason, the Institute of Photogrammetry of the University of Stuttgart examined the new instruments from Zeiss and from Kern. Controlled aerotriangulation was performed with one sub-block of the Appenweier test flight in each case, and the results are presented here.

With a standard deviation σ_0 of 6 µm and an absolute accuracy of 7 µm (planimetry), the high performance standard now achieved in point transfer was demonstrated. Thus nowadays the term "precision triangulation" can also be applied in connection with artificially marked tie points; however, there is still a considerable discrepancy in comparison with the results achieved with signalized points. From the point of view of cost effectiveness, too, times of approximately 2 minutes for transfer and measurement of a tie point can be regarded as highly satisfactory.

In conclusion, the possible future progress of point transfer on analytical stereoplotters or by methods of digital image processing is described.

Photogrammetrische Woche 1981
Institut für Photogrammetrie
Schriftenreihe, Heft 8, 1982

Untersuchungen zur Punktübertragung

Zusammenfassung

Der großen Bedeutung der Punktübertragung für die praktische Photogrammetrie wurde in den letzten Jahren durch die Entwicklung einiger neuer Geräte, die eine Leistungssteigerung in Bezug auf Genauigkeit und Wirtschaftlichkeit bringen sollten, Rechnung getragen. Aus diesem Grund wurden vom Institut für Photogrammetrie der Universität Stuttgart die neuen Geräte der Firmen Zeiss und Kern untersucht. Dabei wurden kontrollierte Aerotriangulationsverfahren mit jeweils einem Teilblock der Testbefliegung Appenweier durchgeführt, deren Ergebnisse hier vorgestellt werden.

Mit mittleren Gewichtseinheitsfehlern von 6 µm und einer Absolutgenauigkeit von 7 µm (Lage) hat sich der hohe Leistungsstand, den die Punktübertragung erreicht hat, aufgezeigt. Damit kann inzwischen von Präzisionsaerotriangulation auch im Zusammenhang mit künstlich markierten Verknüpfungspunkten gesprochen werden, es verbleibt jedoch noch ein deutlicher Unterschied zu den mit signalisierten Punkten erhaltenen Ergebnissen. Auch in wirtschaftlicher Hinsicht konnten Zeiten von etwa 2 Minuten für die Übertragung und Messung eines Verknüpfungspunktes sehr zufriedenstellen.

Abschließend wird noch kurz beschrieben, wie zukünftig die Punktübertragung an analytischen Stereoauswertegeräten bzw. mit Methoden der digitalen Bildverarbeitung ablaufen könnten.

Recherches en matière de report de points

Résumé

Au cours des dernières années, on a tenu compte de l'importance du report de points pour la photogrammétrie pratique par le développement de nouveaux appareils qui devaient apporter de meilleurs résultats dans le domaine de la précision et de la rentabilité. Pour cette raison, l'Institut de Photogrammétrie de l'Université de Stuttgart a examiné les nouveaux appareils des maisons Zeiss et Kern. A ce propos, on a effectué des méthodes contrôlées d'aérotriangulation avec respectivement un bloc partiel de la mission photographique Appenweier. En voici les résultats:

Avec des erreurs moyennes quadratiques d'unité de poids de 6 µm et une précision absolue de 7 µm (planimétrie), le report de points fournit d'excellents résultats. Ainsi il est justifié de parler d'une aérotriangulation de précision également dans le contexte de points de liaison marqués artificiellement. Cependant il y a toujours une différence sensible relative aux résultats obtenus avec des points signalisés. En ce qui concerne le report et la mesure d'un point de liaison, on a obtenu un temps très satisfaisant de 2 minutes.

En conclusion, l'auteur décrit brièvement la façon de réaliser à l'avenir le report de points sur des appareils stéréorestituteurs analytiques ou bien le report au moyen de méthodes d'exploitation digitale d'image.

Photogrammetrische Woche 1981
Institut für Photogrammetrie
Schriftenreihe, Heft 8, 1982

Estudios relativos a la transferencia de puntos

Resumen

La gran importancia que reviste la transferencia de puntos en la fotogrametría práctica ha sido tenido en cuenta en estos últimos años por el desarrollo de unos instrumentos de índole nueva que deberían aportar más exactitud y trabajar de manera más eficiente con respecto a los costes. Por este motivo, el Instituto de Fotogrametría de la Universidad de Stuttgart ha estudiado los nuevos instrumentos presentados por las casas Zeiss y Kern. Para tal fin se han llevado a cabo aerotriangulaciones controladas con sendos bloques parciales del vuelo de ensayo "Appenweier". En la presente conferencia se exponen los resultados obtenidos.

Con la desviación standard σ_0 de 6 µm y la exactitud absoluta de 7 µm (planimetría) se ha demostrado el alto nivel de eficiencia que se ha alcanzado ahora en la transferencia de puntos. Gracias a ello, puede hablarse ahora de "aerotriangulación de precisión" también en relación con puntos de enlace artificialmente marcados; sin embargo, continúa habiendo una discrepancia considerable en cuanto a los resultados obtenidos con ayuda de puntos señalizados. También desde el aspecto económico han satisfecho mucho los tiempos de aprox. 2 min. para transferir y medir un punto de enlace.

Se concluye la exposición del tema describiendo cómo sería realizable en el futuro la transferencia de puntos en estereorrestituidores analíticos o aplicando métodos del proceso digital de imágenes.

Dipl.-Ing. Manfred Sigle,
Institut für Photogrammetrie der Universität Stuttgart,
D-7000 Stuttgart 1, Keplerstr. 11