SEMI-AUTOMATIC MEASUREMENT OF SIGNALIZED GROUND CONTROL POINTS AT DIGITAL PHOTOGRAMMETRIC WORKSTATIONS

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KEY WORDS: Control point library, measurement of signalized points, semi-automatic process, photogrammetric workstation, data compression

ABSTRACT

The measurement of ground control points is the weakest point in the automation of photogrammetric orientation procedures. Automatic interior and relative orientation procedures as well as point transfer modules for aerial triangulation are now available in Digital Photogrammetric Systems. What is still missing are automatic exterior orientation processes because of the lack of a reliable procedure for ground control point measurement.

The paper presents an investigation into the semi-automatic measurement of signalized points. We propose a concept which is based a library of templates with various types of signals. The interactive part of the process is the coarse measurement of a signal by a human operator. With this approximate location the precise measurement is solved by matching taking different templates into account. If a signal is imaged in several photographs a multi-image solution is derived even though the starting value has to be given only in one image. Special attention is drawn to the varying background problem. An experimental investigation is carried out with 36 photographs in which 1714 image points of the imaged signals have to be measured. The experimentally found rate of over 99% of successfully localized signals has exceeded all prior expectations. Furthermore, the accuracy of this automatic measurements of 2.8 μm is 15% better than the 3.2 μm accuracy obtained for the manual measurements. Further, dependency on the image compression rate and on the type and shape of the templates is reported.

1. INTRODUCTION

The automation of photogrammetric image orientation procedures has now been a central topic of research for many years. Today, algorithms for solving the interior and the relative orientation are quite successful and are now integrated in Digital Photogrammetric Systems. Similar progress can be observed in the development of point transfer procedures for automated aerial triangulation. The success of these procedures is substantially a success of image analysis and image matching. In particular, the extraction of prominent points in images and feature based or area based matching of those points are used for the development of robust and reliable processes. In interior orientation the precise measurement depends on matching the image with a more or less binary pattern of the fiducial mark.

The development of algorithms for reliable location of ground control points has been slow over the years. In present work the user of a Digital Photogrammetric System has to measure these points in some manual mode. The general problem in this case is to establish the correspondence between the points on the ground and the images of those points. For automatic processes this 3D to 2D correspondence problem is significantly more difficult than the 2D to 2D correspondence problems mentioned above. One reason is that classical coarse-to-fine processing using image pyramids can not be applied and another successful method for restricting search space and producing approximate values for solving the correspondence problem is not available. A second reason is that in particular natural ground control points, e.g. street crossings, in general appear in a variety of different shapes. Referring to this, the classical discs used for signalization of ground control points are quite simple. For this uniformly shaped targets the chance to be successful in detection and location of the signals increases. But corruption of signals, inhomogeneous background and the usually small size of those signals are problems which make automatic measurement difficult.

A general formulation of a photogrammetric process for automatic ground control point measurement has to take care of the scene interpretation problem. Often sketches are prepared and comments are added to assist an operator in finding the ground control points in the photographs. Without such help it would be also a big problem for a human operator to scan through an image and detect signalized points. The transfer of an operator's knowledge and interpretation capability to a procedure which applies rules on detection and selection of signals and which addresses identification, precise measurement and verification is still far from being solved. For more details please confer Hahn (1993) and Gülch (1995).

In the concept presented in the next section we assume that a human operator is involved in the measurement of signalized points.

2. A CONCEPT FOR SEMI-AUTOMATIC MEASUREMENT OF SIGNALIZED POINTS

Depending on the block configuration and the position within a block signalized ground control points, check points or tie points are imaged, for example, in two, three or six photographs. Only the points in the extreme corners of the block may appear in only one image. Therefore, we aim at a procedure for multi-image measurement of the signals in all images.

The proposed concept

1. collects templates which represent the various types of signals in a library,
2. supposes that the approximate position of the signal in one image is given, e.g. measured manually by a human operator,
3. uses area based multi-image matching to provide the approximate location of a signal in all overlapping images and
4. measures the precise image location of a signal by matching with templates of the library.

In Digital Photogrammetric Systems (DPS) today it is quite standard that image pyramids for all images of a block are available. Further parameters which characterize the block structure completely (like image and strip parameters, flight direction, neighbourhood of images and strips, overlap in p and q, etc.) are also represented in the system. With the image pyramids it is guaranteed that matching processes can operate on different resolution levels. Together with the knowledge on the block parameters coarse-to-fine matching allows automatic point transfer in all overlapping images. Tsingas (1991) has shown that this works well in a feature based solution. In cooperation with the Zeiss company we developed an area based least squares solution for stereo and multi-image matching. With this algorithm matching of one point pair through 7 levels of an image pyramid is performed in about 1.2 seconds on a Silicon Graphics Indigo2 Workstation (R4400/200MHz).

The measurement of a signalized point is started with a semi-automatic preparation step in which the approximate location in one image is defined by the human operator. The determination of the location in all overlapping neighbouring images is solved with the multi-level least squares approach mentioned above.

The measurement process for localization of the signalized points consist of a two step solution. In the first step area based matching (with 6 geometric and 2 radiometric parameters) between the template **T** and the images **1 .. N** is carried out (figure 1).

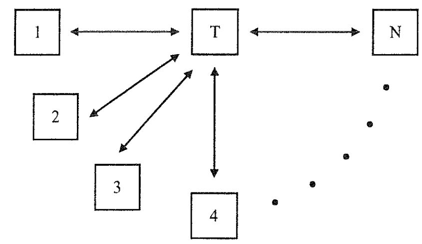


Figure 1: Step 1: template matching

With the estimated transformation parameters the reference point of the template is transferred into all matched images. Then matching back is carried out by changing the role of mask and search image. Because the least squares solution is solved by linearization and adjustment over the estimates in the search image this small unsymmetry may lead to differences in the estimated results of both solutions. In general, the differences will be small because a prerequisite for matching back is that matching from mask to search was successful. If nevertheless a certain difference is obtained this indicates that differences in the image structure of mask and search have an influence on the estimated optimal solutions through the gradient spaces (which are the spaces in which the optimal solution is 0). In addition to the standard convergence criteria inconsistency with matching transferred points back is taken as internal measure for assessing successful matches.

If matching of the template with an image fails this may lead to a situation like that sketched in figure 2.

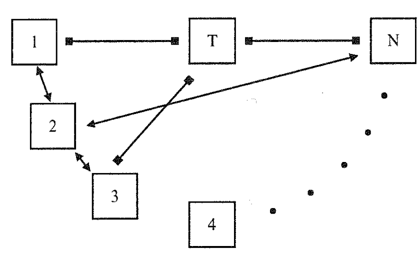


Figure 2: Step 2: completion of failed matches

In this case the pairs **T–1**, **T–3** and **T–N** are processed successful whereas matching **T–2** and **T–4** has failed. Now the second step of the procedure is activated which aims at completing this failures. For that, all successfully matched points of step 1 are now used to carry out image to image matching. At the example of figure 2 this is matching of the pairs **1–2**, **3–2** and **N–2**. If this succeeds for more than one pair then the mean of all estimated locations in figure **2** is calculated. In the same way the process is continued until all missing correspondences are supplemented or all possibilities are exhausted.

The role of the template library is not addressed so far. From a practical point of view it is quite simple to take a given library into account by substituting the template considered so far with a series of templates. But this leads to an interpretation problem because associated with each template is the hypothesis that the template is a reasonable model for the target. Instead of evaluating the matching with one template the algorithm has to choose the best match among all template matches. With the best match the localization and identification of a certain signal is given. For the evaluation we use the results of the self-diagnosis module of the matching algorithm which answers

- with 0 if matching of a template with an image is done perfect,
- with 1 if matching is successful but with lower correlation,
- with 2 if the transfer into an image has to go the indirect way (step 2),
- with 100 if matching fails.

The sum of this values is calculated over all matches of a template with the images of a signalized point and is taken as the description length for evaluating the matching with a specific template. The template which yields the minimal description length is considered to give the best measurements.

In practice we have to take into account that signalization for an image flight is done with relatively small signals. Scanning of the photographs with a moderate pixel size, e.g. with 15 μm, leads to some pixels diameter of the imaged target. Most commonly used are round and square targets or crosses.

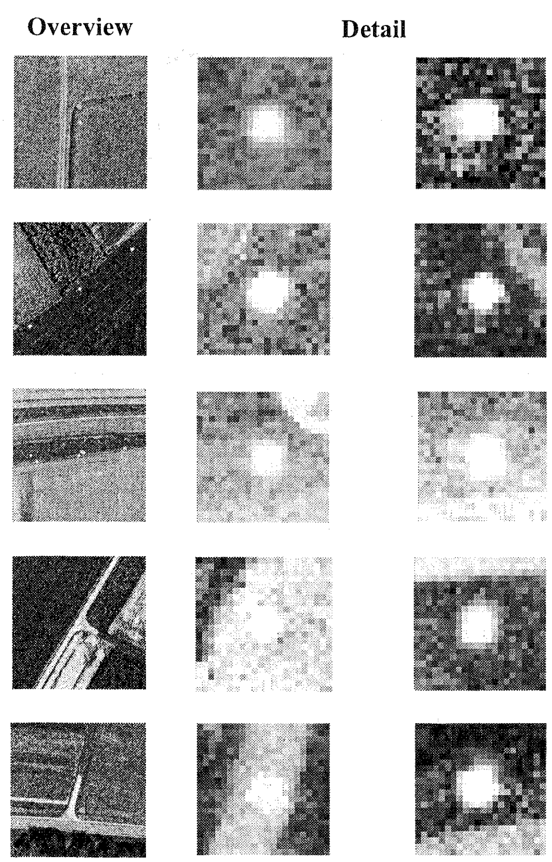


Figure 3: Examples of signalized points. The left column shows overviews, the right columns detailed views (21 $\times$ 21 pixels) of some signals.

Further, the varying background problem is taken into account within the developed algorithm. In practice the signals are located in natural terrain which makes proper modelling difficult. Some examples taken from the flight experiment used in this investigation are plotted in figure 3. Elimination of inhomogeneous background within the matching process is managed by weighted least squares. The weights can be derived from the template image, for example, by creating a weighting mask proportional to the gradients of the template. Another possibility is to use a circular weighting function which steeply descend outside a certain radius. In the experiments the circular weighting function with a binary inside - outside decision is used.

3. EXPERIMENTAL INVESTIGATIONS

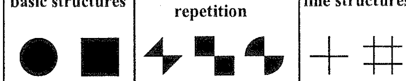
In the experimental investigations we process the image data of a test flight experiment which was carried out in 1995. The images have been taken with a RMK TOP 15, the photo scale is 1 : 13 000, the flying height above ground 2000 m. The block covers an area of 4.7 km $\times$ 7.2 km. Three strips are flown in east-west direction with 7 photographs in each strip and an overlap of of 60 % within and across the strips. Another three strips are taken in north-south direction with 5 photographs per strip and an overlap of p = 60 % and q = 30 %. The photographs are scanned with a pixel size if 15 μm which give 7.9 Gbyte of data for the 36 digital images. With 200 square targets the test field has been signalized. The size of a target on the ground is 1 m^2.

Altogether, 1714 image points of the 200 signalized targets have to be measured in the 36 photographs of the block. Most of the signals are imaged in three, six, nine and twelve images, just one appears in 15 images.

Before we discuss the empirical results of the investigation we first want to deepen some aspects on the recognition of simple-shaped signals.

3.1 Aspects on the Recognition of Signalized Points

Theoretical dependences between recognition and shape of a signal in the context of semi-automatic ground control point measurement can be solved by simulation. In fact there exist simulation studies, for example Kaiser et al. (1992), on the recognition of patterns used for optical positioning of printed circuit boards. In this work different types of patterns are evaluated as shown in figure 4.



	basic structures		structures with repetition			line structures	
number of correlation maxima	1	1	3	3	3	1	9
gradient of autocorrelation	0.06	0.07	0.15	0.10	0.10	0.17	0.27

Figure 4: Features of the autocorrelation function (adopted from Kaiser et al., 1992).

The most important result of that work can be summarized as follows. The risk to fail with an area based matching technique increases in structures with repetition, because the number of correlation peaks is higher than one. For precise localization of a structure it is advantageous to have a steeply descending autocorrelation function. The gradients listed in figure 4 indicate that the cross structure is superior to the circular and square shaped structures. Unfortunately, the length to width ratio in line structures is not very favourable for signalization. Given a minimum width, e.g. one pixel in image space, this implies relatively large targets. If the length to width ratio becomes smaller, the advantage of crosses will disappear. In consequence, there is no reason to change the simple target shapes used so far. Only the size of the targets should increase to a certain extend because this improves the measurement in the digital domain.

For a further discussion on identification and discernibility of simple shaped structures cf. Geiselmann and Hahn (1994).

The templates used in the experiment are plotted in figure 5.

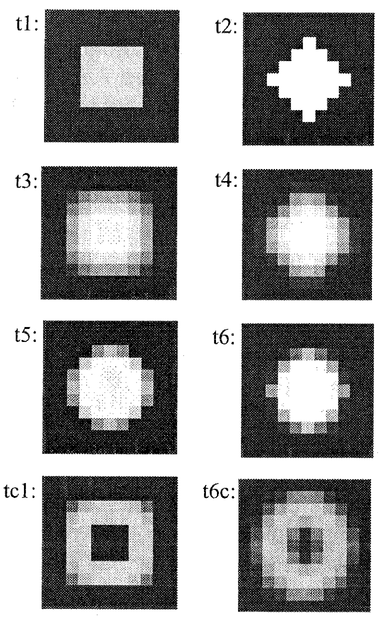


Figure 5: The templates used in this experiment.

Template t1 and t3 represent a square target and its unsharp representation. By rotation of this templates t2 and t4 are obtained. The templates t5 and t6 are discrete versions of circular shaped targets. The size of the bright region in this templates is about 5 $\times$ 5 pixels. Six further templates t1c to t6c are generated by calculating images of gradient strength of t1 to t6.

In the experiment the templates are used pairwise, e.g. t1 and t2, so that the matching with the minimum description length criteria described above leads to a decision on which of both templates gives the best measurement.

3.2 Matching without Special Treatment of Background Noise

If matching is carried out without giving respect to the background problem the following result is obtained (table 1).

Table 1: Matching result of template matching

Template type	Matches successful rel. [%]	Matches successful abs.	Matches failed abs.	σ_0 [μm]
t1/t2	74.2	1272	442	2.79
t3/t4	75.9	1301	413	2.85
t5/t6	55.5	952	762	2.90

The measurement accuracy indicated by σ_0 of the block adjustment is about 3 μm or 1/5 of the pixel size which is a quite good accuracy for signals with a size of 5 times 5 pixels. For comparison a **manual measurement** is carried out for all 1714 image points and an **accuracy of 3.17 μm** is obtained. The success rate of 75 % for the sharp and unsharp square is relatively low. And really bad is the 50 % rate obtained for the circle.

3.3 Adjusting the Template Size

To assess the dependency on the background the matching is carried out with various window sizes. Technically a circular weighting function is introduced into matching and binary weighting is used to eliminate all information outside a certain radius.

Table 2: Dependency on the window size

Templ. type	Rad. pixel	Matches successful rel. [%]	Matches successful abs.	Matches failed abs.	σ_0 [μm]
t1/t2	5	99.4	1704	10	2.80
	6	99.5	1705	9	2.81
	7	99.1	1699	15	2.81
	8	98.7	1692	22	2.78
	9	98.7	1692	22	2.78
	10	98.2	1683	31	2.76

The results (table 2) show at first a very high rate of successful measurements. The absolute number of failures is up to an aperture radius of 10 pixel only 31 (but jumps over hundred for radius 11). Thus for these signals the background of up to 4 or 5 pixels width around a target has no negative influence on the measurement of the signal. An expected improvement of the overall accuracy obtained with increasing window size can not be observed from the table. But the obtained level of 2.8 μm is 15 % better than the 3.2 μm accuracy obtained for the manual measurements. The conclusion here is that the proposed procedure is able to measure the signalized points at least with the same accuracy as this could be done by a human operator at Digital Photogrammetric Workstations.

3.4 Taking Compression into Account

The big storage capacity needed to hold the digital images of a block on a disc is still a weak point of Digital Photogrammetric Systems. Therefore, it is quite convenient to use compression algorithms such as JPEG. A measure for choosing the amount of compression in JPEG is the so-called Q-factor. The relation between Q-factor and compression rate depends on the texture in the images. This dependency is shown for this image block in figure 6.

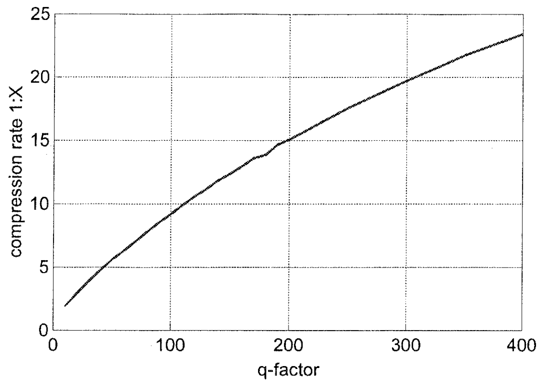


Figure 6: Compression rate as a function of the Q-factor

Of primary interest is the dependency of image compression on the measurement precision and on the success rate. This is plotted in figures 7 and 8. In this case templates t1/t2 are used with a window size of 9 pixels radius.

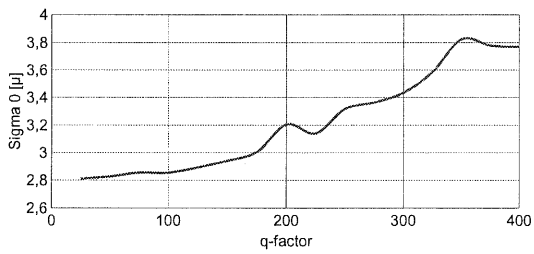


Figure 7: Measurement precision vs. Q-factor

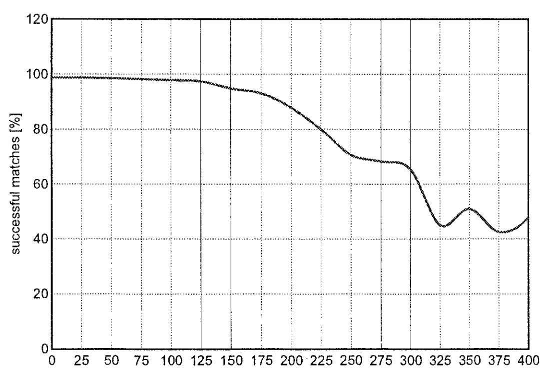


Figure 8: Success rate vs. Q-factor

A deterioration of the measurement precision can be observed with values from 2.8 μm to 3.7 μm if the Q-factor increases from 0 to 400. On the first view a loss of accuracy of around 35 % seems to be a relatively small number, having in mind that the compressed block reduces the volume for storage to 330 Mbyte. But if we look at the number of successfully matched signals this rate is below 50 % at the high compression factor. Thus it is mainly due to the matching procedure that a relatively good accuracy level is obtained by eliminating those points which do not fit any more under compression. The figures show also that, for example with a compression rate of 10 (Q around 100) still a reasonable result is obtained with 98 % successfully measured signals and without significant loss of accuracy.

3.5 Comparison with Different Types of Templates

With the last experiment we want to explore the influence of the different types of templates (figure 5) on the measurement process. For this comparison only three very different compression rates are considered with the Q-factors 0, 200, 400. A priori it is to be expected that because of the usually small resolution of signalized points in images the importance of different templates is not as big as it would be if a signal is imaged over a image area of e.g. 50^2 or 500^2 pixels. The result of the template combination t1/t2 was discussed in the section before and is listed here for comparison with the results of other template combinations (tables 3 and 4).

Table 3: Matching with other template combinations

Templ. type	Q-factor	Matches successful rel. [%]	abs.	failed abs.	σ_0 [μm]
t1/t2	0	98.7	1692	22	2.78
	200	87.9	1506	208	3.18
	400	47.8	819	895	3.74
t3/t4	0	96.5	1654	60	2.75
	200	79.4	1361	353	3.11
	400	31.6	542	1172	4.01
t5/t6	0	93.4	1600	114	2.78
	200	84.0	1439	275	3.14
	400	27.3	467	1247	4.14

The number of successfully matched points found with template combination t3/t4 is significantly smaller than the number obtained with the t1/t2 combination. And the difference becomes bigger with increasing compression rate. This means, that unsmoothed structures are more advantageous in the case of this small signals. The obtained quota in matching with the templates of circular structure t5/t6 is still some percentage points smaller than that of template combination t3/t4. A comparison of the obtained precision values between the three template combinations shows the familiar result of nearly equal precision at equal Q-levels which already was observed from table 1.

A further concentration on the contours of the signals is the reason for selecting the templates t1c to t6c (figure 5). They are generated calculating templates of gradient strength of t1 to t6. The images in this case are preprocessed in the same manner and matching is carried out on this representation level.

Table 4: Contour related template representation

Templ. type	Q-factor	Matches successful rel. [%]	abs.	failed abs.	σ_0 [μm]
t1c/t2c	0	86.8	1488	226	2.90
t3c/t4c	0	65.4	1121	593	2.99
t5c/t6c	0	85.0	1456	258	2.92

Even though no compression is taken into account in this test a relatively high quota of failures is obtained with all template combinations. This can be explained by the fact that in the gradient images noise is amplified with a negative impact on matching.

4. CONCLUSION

In this papers we presented a procedure for semi-automatic measurement of signalized points at Digital Photogrammetric Workstations. In general signalized targets may appear in several images. Therefore, we aim at solving the target location by adding multi-image constraint. For both, template matching and image matching an area based least squares solution is used. Further aspects like the varying background problem are taken into account by the procedure.

The experimental investigation with 1714 images of signals in a block with 36 photographs have shown that the proposed procedure was quite successful by measuring 99 % of all image points. Furthermore, the accuracy of this automatic localization with 2.8 μm is 15 % better than the 3.2 μm accuracy obtained for the manual measurements. The results obtained using compressed image data indicate no significant loss of precision and success rate up to a compression ratio of 1:10.

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