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# Automatic Control Point Measurement

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**ABSTRACT**

Nowadays the tenor of reports on applications of digital photogrammetric procedures consists of a unison message: processing modules of automatic image orientation are available in digital photogrammetric systems and with them the productivity is much higher than with all existing conventional photogrammetric plotters. In fact, interior and relative orientation procedures as well as automated aerial triangulation have matured. Unfortunately this positive balance is not generally valid for automatic control point measurement which is required in automating exterior orientation.

In this paper we review developments on automatic measurement of ground control and present an investigation on (semi-)automatic extraction of signalized points. The philosophy behind this investigation follows a pragmatic idea: for signalization of a block a simple signal structure is used which promises a high success rate in detection and location of control points. Experimentally a block of 36 photographs was processed with totally 1714 image points of imaged targets. The measurement rate of over 99% of successfully localized signals is remarkably high. Furthermore, the accuracy of this automatic measurements of 2.8 µm is 15% better than the 3.2 µm accuracy obtained for manual measurements.

## 1. AUTOMATION OF EXTERIOR ORIENTATION

Automatic exterior orientation is dominated by research which so far diverges in two completely different directions. On one hand there is GPS and INS technology which permits direct measurement of position and attitude parameters. In principle, a multisensor camera system with integrated GPS/INS sensors produces exterior orientation parameters without any ground control which is also called geo-referencing. Consequently photogrammetric control points which primarily serve for datum transform from a local sensor system to a global geodetic coordinate system would become obsolete. That this assessment does not bear closer examination is outlined by Ackermann (1997). He concludes that the analysis of accuracy performance discloses that especially INS does not yet meet the high photogrammetric demands. Moreover, control and elimination of systematic errors and mainly the weak reliability of GPS geo-referencing make the use of some control points mandatory.

On the other hand there is the traditional indirect determination of exterior orientation. Control information must be provided externally and research tries to solve the measurement of control points or structures in digital images. Performance expectation on automatic measurement defined by human operator's efficiency is high. An operator measures control points fairly quick, reliable and accurate. There is a certain dependency between achievable precision and type of control information (signalized points, selected natural points and man-made structures, e.g. buildings or street crossings) whereas highest precision is usually obtained with signalized points. An overall measurement process consists of detection, identification and precise location of imaged control points. Unfortunately, the automation of these three steps of control point measurement is more difficult than photogrammetric image measurement tasks like interior orientation or point transfer. This is the major reason why the development of algorithms for reliable location of ground control points has not shown much progress during the last decade.

## 2. AUTOMATION OF GROUND CONTROL POINT MEASUREMENT

The general problem of measuring ground control is to establish correspondence between a given model of a control point and its representation extracted from an image. If control information is imaged in two or more photographs, multiple image matching provides restrictions and additional information for model to image correspondence. For exterior orientation a broad spectrum of

representation levels of ground control information is suggested and to some extend it has been experimentally used.
There is the fairly old idea to use image chips which represent ground control points iconically. Image chips typically cover a local area around control points but theoretically large area image information given by an ortho-image could be used as well. Even though a simple area based matching scheme might localize control points sufficiently the deficiency of this approach is obviously with existing image data. A preceding image flight is required which must be triangulated to get image chips together with its object coordinates. Further temporal variations between images may prevent matching from being successful. For old imagery the change detection problem mixes up with control point detection so that in this case automatic processing for exterior orientation is not feasible.
Basically the same revision problems exist if map or GIS data are used. Matching performs on a symbolic representation level with structures consisting of points, linear and area-type features. Further, relations might be included explicitly. Feature based matching, e.g. of polygons, and relational matching are used to compare the image and model descriptions on a symbolic representation level. Feature based and even more relational matching of control structures is acknowledged as a general method which could solve the problem even if no approximate values are given to restrict search space significantly. Unfortunately there are still big problems in extracting a useful symbolic image description to an acceptable level of confidence and reliability. Because of these problems the efforts in automating exterior orientation along this line are very limited.
Closest to practical needs are developments which are tailored for specific applications. An example is given by Schickler (1992) who uses three dimensional wire frame models of houses to determine the exterior orientation for orthophoto production at the Landesvermessungsamt Nordrhein-Westfalen. More examples on some early work are discussed in a review paper on control point measurement presented at the last photogrammetric week (Gülch, 1995). Recent work follows this trend of developing tailored solutions. Experiments indicate that processing strategies which focus on specific landmarks and signalized points rather than on a general generic type of topographic map information show first success. Quite interesting to note is that often precise location is based on a raster representation of control information. Because fully automatic detection and identification is still too difficult a minimum of interactive support is often given. Thus, strictly speaking most proposals include semi-automatic processing.
The approach presented by Drewniok and Rohr (1996) was developed for urban large scale images. They focus on the use of manhole covers as landmarks. The applied model type and an intensity image of a manhole cover is depicted in Figure 1.

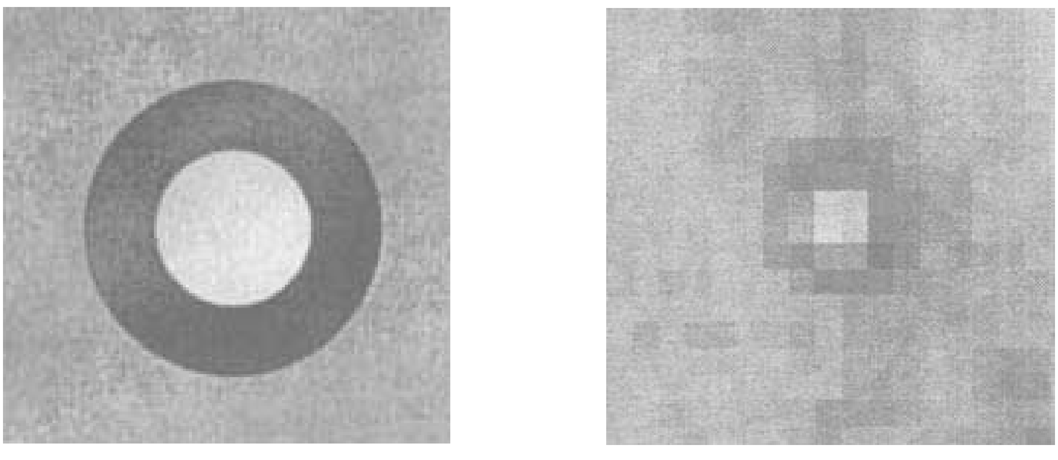

Figure 1: Unblurred model of a manhole cover (left) and intensity image (right). Taken from Dewniok and Rohr (1996).

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The model consists of a bright disc surrounded by a dark concentric ring which is embedded in homogeneous background. Three template parameters of a blurred version of this model are adjusted in a training phase using an operator selected representative sample of imaged manhole covers. The detection is then executed automatically based on cross correlation. Localization is solved by least squares adjustment and identification uses geometrical invariants based on relative distances of landmark triplets. Experiments with image data in which about 400 to 500 manhole covers have been visible in an image have shown that 25% to 30% of them are extractable with the used model. A correct exterior orientation was found using robust techniques to cope with false detections and with manhole covers which had not been included in the cadastral database.
The work presented by Pedersen (1996) relates also to large scale aerial photographs. His interest is in landmark types which cover large areas like road intersections and parking lots. The three-dimensional geometry of those objects is taken from a digital map. For approximate projection into image space the flight plan parameters are used. By vector-to-raster conversion target templates are generated for which an example is shown in Figure 2.

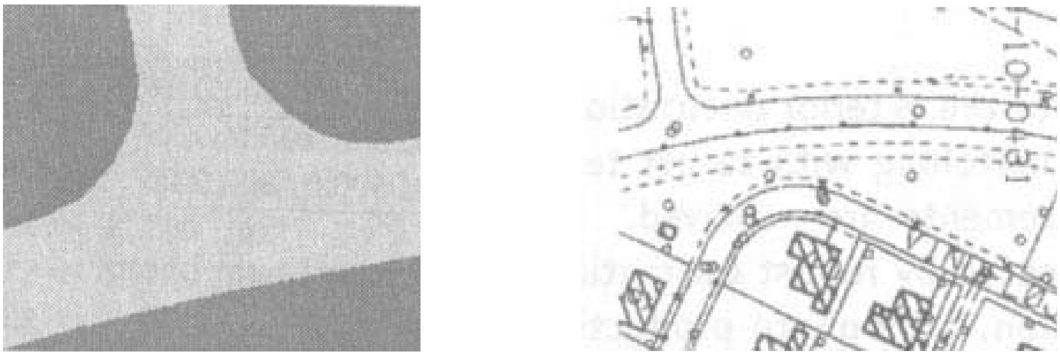

Figure 2: Target template of road intersection (left) and map example (right). Taken from Pedersen (1996).

Conceptually this approach includes coarse-to-fine processing with several image pyramid levels, localization by employing cross correlation followed by a least squares fit to determine image coordinates and computation of improved image orientation parameters by means of a robust bundle adjustment. The reported results are encouraging. RMS differences calculated for control point coordinates and projections centre coordinates indicate that dm-quality can be obtained. But the results also reveal problems with high resolution pixel sizes. At 15 µm, 30 µm and 60 µm there is not enough robustness to deal with influences of shadows, vegetational impact, dirt on streets and not to speak of road users. Therefore, a further processing step might be to proceed with smaller ground control objects on high resolution levels.
A critical point in this template based landmark approaches is the radiometric description of objects and background within the template region. But it seems to be a procedural advantage that extraction of a high level description with its well-known unreliability is not required. Of course, raster based modelling of natural landmarks will never be perfect and manifold influences like inhomogeneous street surface properties or shadows might be so significant that generally a rather low detection rate must be expected. Therefore, those approaches must be prepared to work well if the number of landmarks for which the raster model fits excellent to the imaged landmark is small.
If signalization is taken into account modelling of signals is quite easy compared to natural landmarks. With a simple disc or square shaped signal of properly selected size we have been very successful in measuring the signal precisely and with a high success rate (Hahn et al., 1996). Of course, the drawback of signalization is that surveying for each signal might be rather costly. But we have to bear in mind that with increasing use of airborne GPS fewer control points are required. Furthermore, in

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some projects most precise control points are essential which in turn favors signalized points over natural landmarks.
In the next section our concept for semi-automatic measurement of signalized points is summarized. Investigations are carried out with different template shapes, special treatment of background and image compression for which the experimental results are reported in section 4.

## 3. 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 points in the extreme corners of a block may appear in just one image. Therefore, we aim at a multi-image measurement procedure for precise location of signals in all images.
Our routine for control point measurement should be able to benefit from existing technologies. If airborne GPS is used we have the situation that after carrying out GPS aerial triangulation at least good approximate values for all control points in all images are easily computable. If no GPS is used an aerial triangulation with a minimum number of 3 or 4 control points will serve for the same purpose. In this case the approximate position of those 3 or 4 control points is assumed to be measured manually in one of the corresponding images. This starting assistance eliminates the need for a more difficult detection and identification strategy. A further existing tool which we want to employ is a least squares multi-image matching routine. Its capabilities include coarse-to-fine matching to deal with coarse approximate values and self-diagnosis which evaluates whether matching was successful or not with respect to a required accuracy level. For more details cf. Hahn et al. (1996).

The proposed concept for signalized point measurement

1. includes collection of templates which represent various types of signals in a library,
2. supposes that the approximate position of a signal in at least one image is given,
3. uses area based multi-image matching to provide consistent approximate locations of a signal in all overlapping images and
4. measures the precise image location of a signal by matching with templates of the library.

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 3).

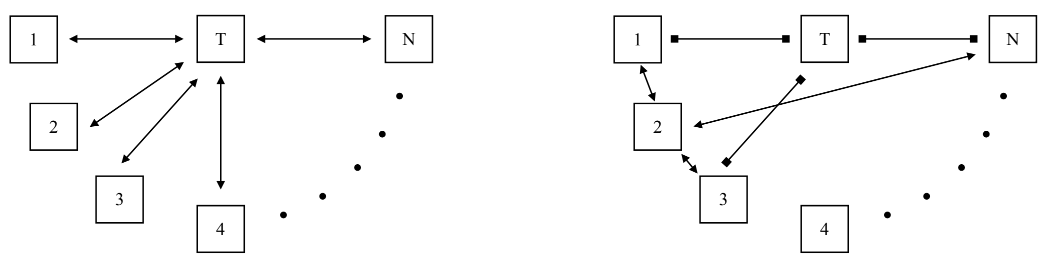


Figure 3: Step 1: template matching (left), Step 2: strategy dealing with failed matches (right).

With the estimated transformation parameters the reference point of a template is transferred into all matched images. All these points are transferred back using the estimates found by matching with exchanged roles of mask and search image. No inconsistencies will be found in the back-transferred

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location of the template reference points if model and image transform well into each other. Otherwise it is a property of the non-linear matching routine that differences between the image structure of mask and search image will show up in residuals of the back-transferred template reference point locations. We found this property of the routine as a very efficient selfdiagnosis feature for guaranteeing a certain accuracy of point transfer. In addition to the standard convergence criteria within matching the selfdiagnosis feature is taken as further measure for assessing successful matches.

If matching of the template with an image fails this may lead to a situation like that sketched in the second plot of Figure 3. 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 3 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 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, of course, leads to an interpretation problem because associated with each template is the hypothesis that the template is a valid model for the target. Instead of evaluating matching with one template the algorithm has to choose the best match among all template matches. With the best match localization and identification of a certain signal is given. A simple cost function is defined based on the self-diagnosis of the matching algorithm. We have costs of 0 if matching of a template with an image is done perfect, costs of 1 if matching is successful but with lower correlation, costs of 2 if transfer into an image has to go the indirect way (step 2), and high costs of 100 if matching fails. The sum of these costs is calculated over all matches of a template with images of a signalized point. If the costs for all the different templates are determined the template which produces minimal costs is considered to be the optimal solution delivering the best measurement.

Varying background is another conceptual issue which is taken into account within the developed algorithm. In practice the signals are located in natural terrain which makes proper modelling of background difficult. To illustrate this problem some examples are taken from the investigated image flight data and are plotted in Figure 4. 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 descends outside a certain radius. In the experiments a circular weighting function with a binary inside - outside decision is used. This means, outside of a certain radius all background is eliminated.

## 4. EXPERIMENTAL INVESTIGATIONS

In this section we summarize our investigation with image data of a test flight experiment which was carried out in 1995. The images have been taken with a RMK TOP 15, photo scale is 1 : 13000, flying height above ground 2000 m. The block covers an area of 4.7 km x 7.2 km. Three strips are flown in east-west direction with 7 photographs in each strip and an overlap 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%. There have been 200 signalized square targets in the test field. The size of a target on the ground is 1 $m^2$. The photographs are scanned with a pixel size of 15 µm which gives 7.9 Gbyte of data for the 36 digital images.

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, and even one appears in 15 images.

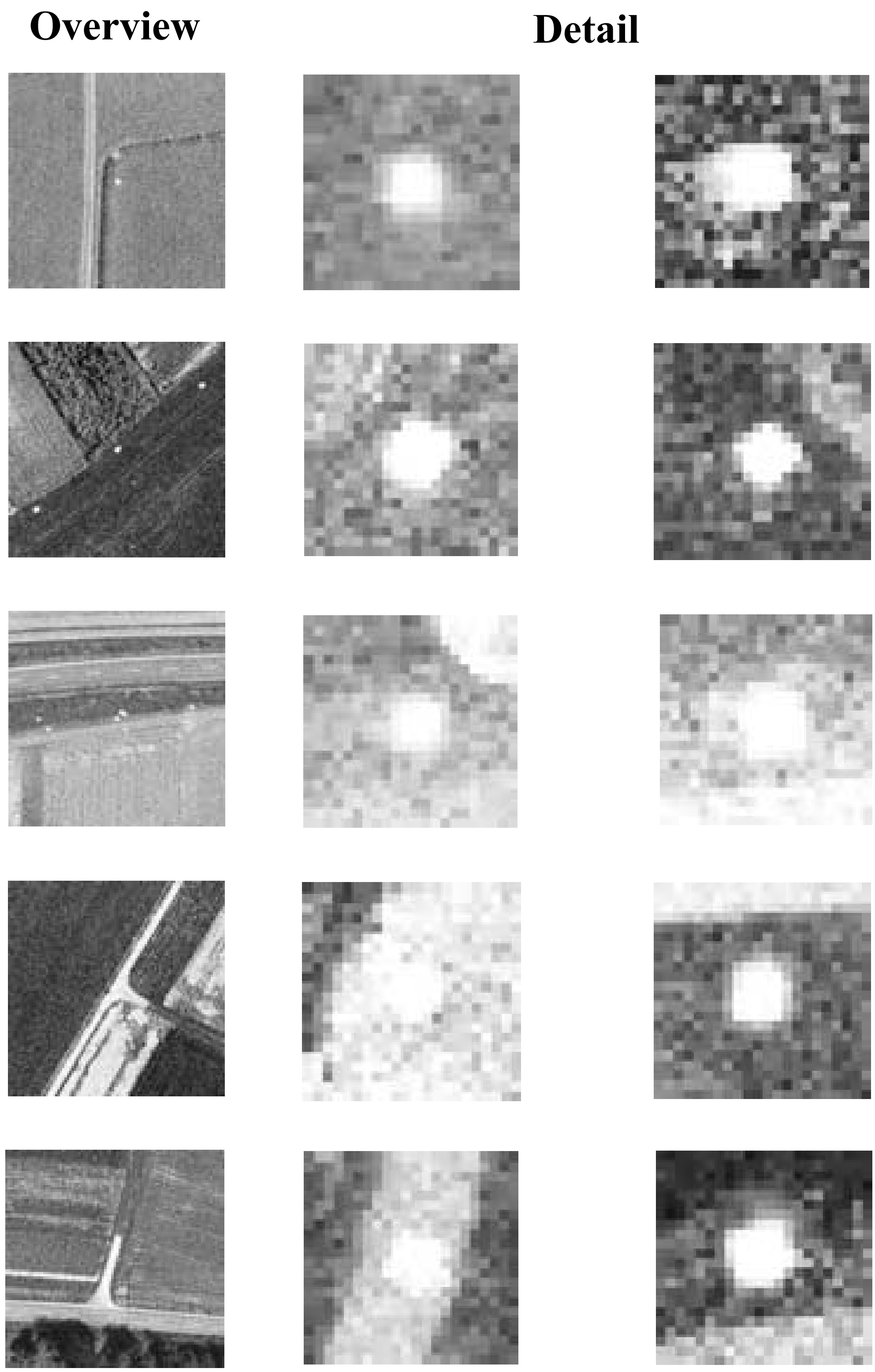


Figure 4: Examples of signalized points. The left column shows overviews, the right columns detailed views (21 x 21 pixels) of some signals.

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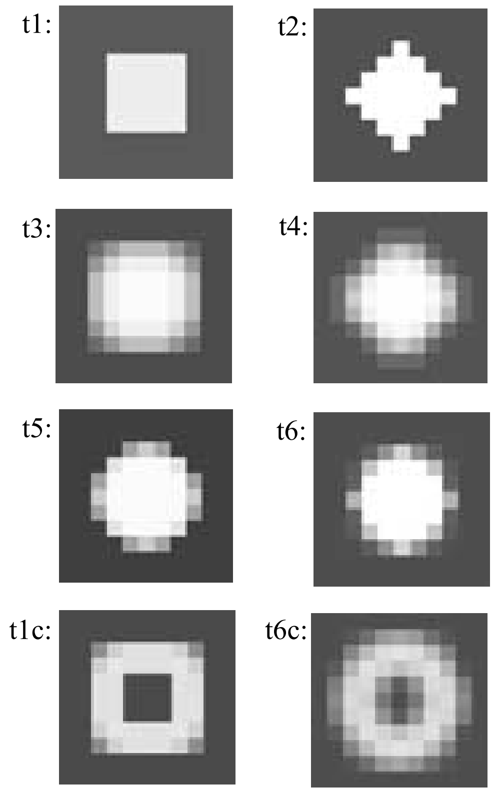


Figure 5: The templates used in this experiment.

To investigate the importance of an exact template model of ground control points for localization a library of templates is generated which is shown in Figure 5.
Templates 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 x 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 together t2, so that matching with the cost function criteria described above leads to a decision on which of both templates gives the better result.

### 4.1 Matching without Special Treatment of Background

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

| **Template type** | **Matches** **successful** rel. [%] | abs. | **failed** abs. | $\sigma_0$ [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 |

Table 1: Matching result of template matching.

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The measurement accuracy indicated by $\sigma_0$ 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 by 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 very bad is the 50% rate obtained for the circle.

## 4.2 Using different Template Sizes

To assess the dependency on 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.

| **Template type** | **Rad.** pixel | **Matches** **successful** rel. [%] | abs. | **failed** abs. | $\sigma_0$ [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 |

Table 2: Dependency on the window size.

The results (Table 2) firstly show a very high rate of successful measurements. The absolute number of failures is only 31 up to an aperture radius of 10 pixels (but increases strongly for larger radii). Thus for these signalization the background of up to 4 or 5 pixels width around a target had no significant negative influence on the measurement of the signal. That this can not be a general valid rule is obvious. It rather confirms that the instruction to select local areas for signalization in the terrain with a homogeneous land cover was carefully taken into consideration. A closer look to the examples of Figure 4 shows that all 10 control points except the one at the bottom of column 2 are matched successful with a radius of 6 pixels. But already with 10 pixels radius matching fails for 7 of them. 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 manual measurements.

## 4.3 Taking Compression into Account

The big storage capacity needed to hold an image block on a disc is still a weak point of Digital Photogrammetric Systems. Therefore, it is quite important 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.

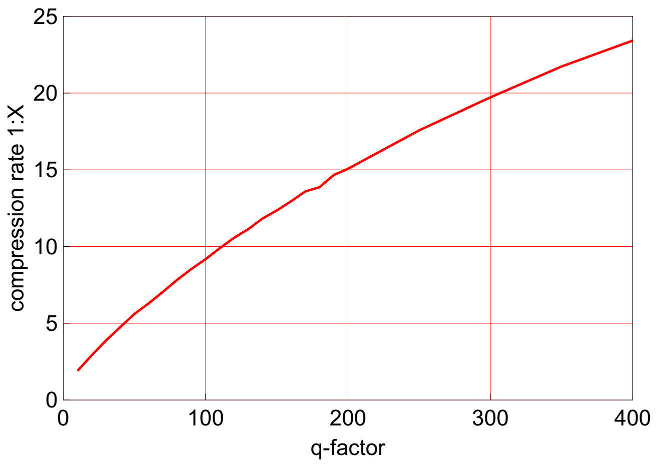


Figure 6: Compression rate as a function of the Q-factor.

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

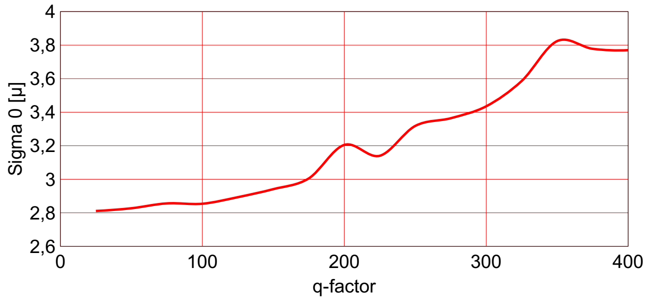


Figure 7: Measurement precision vs. Q-factor.

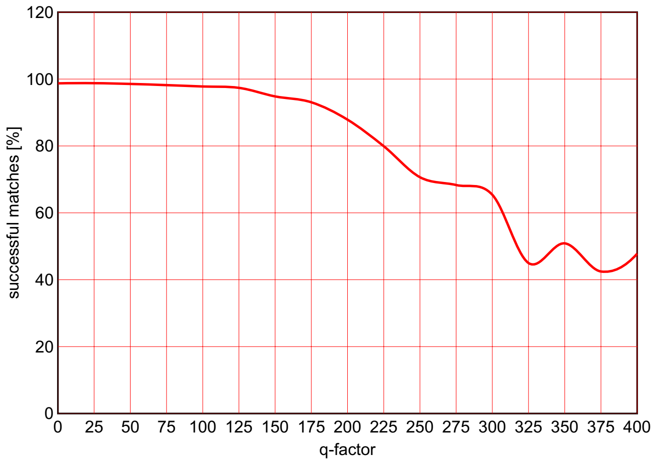


Figure 8: Success rate vs. Q-factor.

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As expected a loss of measurement precision must be observed with higher compression rate. The values range 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 from 7.9 Gbyte to 330 Mbyte. But if we look at the number of successfully matched signals this rate is below 50% at high compression. This clearly points out a main property of our matching procedure: a high accuracy level is achieved 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 control points and without significant loss of accuracy.

### 4.4 Comparison with Different Types of Templates

With the last experiment we want to explore the influence of 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 together with the results of other template combinations (Tables 3 and 4).

| **Template type** | **Rad.** pixel | **Matches** **successful** rel. [%] | abs. | **failed** abs. | $\sigma_0$ [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 |

Table 3: Matching with other template combinations.

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 case of these small signals. The obtained quota in matching with templates of circular structure t5/t6 is some further 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 gradient representation level.

| **Template type** | **Q-factor** | **Matches** successful rel. [%] | abs. | **failed** abs. | $\sigma_0$ [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 |

Table 4: Contour related template representation.

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.

## 5. CONCLUSION

We still have to notice a lot of critical assessments that automatic exterior orientation is waiting for a breakthrough. Nevertheless, we have a certain optimism that with recent developments on measuring manhole covers, street crossings and signalized control points a good step forward towards an automatic solution is done. Characteristic of this developments is that they are tailored for specific applications and circumstances rather than solutions for a large variety of ground control structures. The procedure presented in this paper focuses on raster representations of ground control information. The experiments have shown that processing of a large number of signalized control points was quite successful by measuring 99% of all imaged signals. 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. By using different window sizes the matching algorithm is able to cope with disturbances of background in the local neighborhood of a signal. 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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