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RESEARCH ARTICLE

THE PROBLEM OF USING AND MEASUREMENT OF IDENTIFIABLE GROUND CONTROL POINTS ON HIGH RESOLUTION AERIAL IMAGES

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ABSTRACT: This paper shows the influence of the selection of photogrammetric control points as natural, identifiable points instead of signalized, premarked control points on the results of aerial triangulation of high-resolution aerial images with GSD below 10 cm. In the experiment, different selections of controls were tested using point-type and linear-type points with measurement of their centre or corner. In the experiment, 2 blocks with GSD of 5 and 10 cm were selected using the same measurements in 4 tested approaches with sets of natural identifiable points used by comparing the result with the reference variant. The experiment proves the possibility of using natural controls instead of premarked controls for images of urban areas. This can significantly reduce the cost of photogrammetric missions in urban areas where it is easy to find uniquely identifiable control points that can be used for image orientation.

1. INTRODUCTION

Measuring the development of aerial photographs requires photogrammetric ground controls (so-called ground control points - GCP), i.e. points with XYZ coordinates measured in the terrain by geodetic methods (GNSS, electronic tacheometry, etc.). They can be "natural" control points (clearly identifiable field details, photographed on the pictures), or artificially premarked (signalized) control points (e.g. cross-shaped signs painted on a solid asphalt or concrete surface, or painted on the target and fixed to a soft ground surface).

In the latter case, control points should be planned and premarked before taking photos, because only then they will be photographed on the pictures. Laying, maintaining and measuring signalised (premarked) markers is time-consuming and expensive, and for years it was required to reduce the number of markers limited firstly with using GNSS/INS observation (Wicherson et al., 2000). In the case of natural control points, which can also help in decreasing amount of field work, there is no need of premarking, as they can be planned, identified and measured after the completion of the photo flight mission.

The disadvantage of natural points is the ambiguity of their precise identification in the terrain, and we say that their measurement is contaminated with an identification error. This error depends on the traceability of the field detail itself, adopted as a control point. This problem does not exist for points premarked with artificial targets (e.g. a white cross on a dark background). Here the identification error practically does not occur. Additionally, photogrammetric measurements can implemented in many applications only in case of premarking and planning of control points measured in direct measurements as tie points within aerial triangulation with the highest accuracy (Pyka and Myszka, 2015; Pyka *et al*., 2016).

The identification error depends on the traceability of the detail itself and does not depend on the images. This error is more significant for photos on a larger scale (small ground sampling distance – GSD) than for medium or small-scale photos. With this in mind, natural control points are used for smaller-scale photos, and premarked points for large-scale photos.

There are many guidelines including the issue of premarking (targeting) and using control points in aerial photogrammetry (Department of Transportation, 1998; Jenkins, 2005) and lidar (Davidson *et al*., 2019) missions. In photogrammetric practice in the recent past in Poland, the recommendation of artificial premarking was used for aerial photographs intended for mapping in scales 1: 2000 and larger, which corresponds to the scales of images 1: 8000 and larger. With the development of digital cameras (the first decade of the present century), a simple translation of this recommendation from the past was made: it is recommended to premark the control points for images with spatial resolution GSD lower than 0.15 m (Główny Geodeta Kraju, 1999; Regulation, 2011).

This simple recommendation comes from the aim of finding the equivalence of the resolution of analogue images characterized by their scale and digital photos characterized by their ground sampling distance. However, the above recommendation does not take into account other factors that may be of importance here, such as the different radiometric quality of both groups of photos, modern automatic methods of measuring and developing photos, various applications of contemporary photos (more diverse than before) and other factors determining the increase in the quality of digital photos compared to their analogue counterparts.

Considering the current state-of-the-art in aerial photogrammetry, the question arises of whether the recommendations adopted and put into practice regarding artificial premarking of control points are correct nowadays in the case of very high aerial images captured by photogrammetric cameras. How does the lack of premarking affect the accuracy of the photo orientation process?

The answer to such questions has a measurable economic sense: terrain premarking of control points is a rather troublesome and time-consuming process, and photogrammetry practitioners would like to avoid this stage altogether. This motivated us to undertake research aimed at determining the impact of the lack of premarking and the possibility of replacing it with natural points in the aerotriangulation process of high-resolution images with GSD lower than 10 cm.

2. METHODOLOGY ADOPTED

It was decided to solve the problem with a multi-variant adjustment of the aerial triangulation high-resolution image blocks based on the same image measurements and different photogrammetric ground control options as follows:

- Basic option (option_0) – control points premarked in the terrain, most often with a cross sign;
- Variant of identifiable control points (option_1) **-** centres of point-type objects. The control points are the centres of point-type objects, e.g. centres of manhole covers, armature elements, or clearly identified intersection of linear objects;
- Variant of identifiable control points (option_2) **-** corners of point-type objects. The control points are the corners of point-type objects, e.g. corners of rectangular manholes.
- Variant of identifiable control points (option_3) **-** centres of linear-type objects. The control points are the centres of linear-type objects, e.g. the centre of the short edge of the line painted on the road.
- Variant of identifiable control points (option_4) **-** corners of linear-type objects. The control points are the corners of linear-type objects, e.g. the corner of a horizontal line painted on the road.

All identifiable control points were selected in the vicinity of the signalized points (option_0). This means that all photo blocks (5 blocks) consisted of the same photos and had the same number of control points with a very similar surface distribution. Independent adjustment of photo blocks allowed assessing the influence of the premarking method used on the results. Example of selecting different type control points in one area in nearby of referenced signalized control point was illustrated in Figure 1. Example identifiable control points in both types: point and linear are illustrated in Figure 2 and Figure 3. These figures show photographs identifying details of control point (point-type, linear-type) measured in a field and their view in aerial photo. They show the methodology based on measuring different details of natural control points to prove their proper application and accuracy in aerial triangulation of high resolution aerial images.

Figure 1. Example localisation of different type control points in selected options of experiment methodology

Figure 2. Examples of natural point-type ground control points used in experiment variants: centre of point-type object (option 1) (a, d), corner of point-type (option 2) (b, e) and the view of these identifiable control point on aerial photo (c, f)

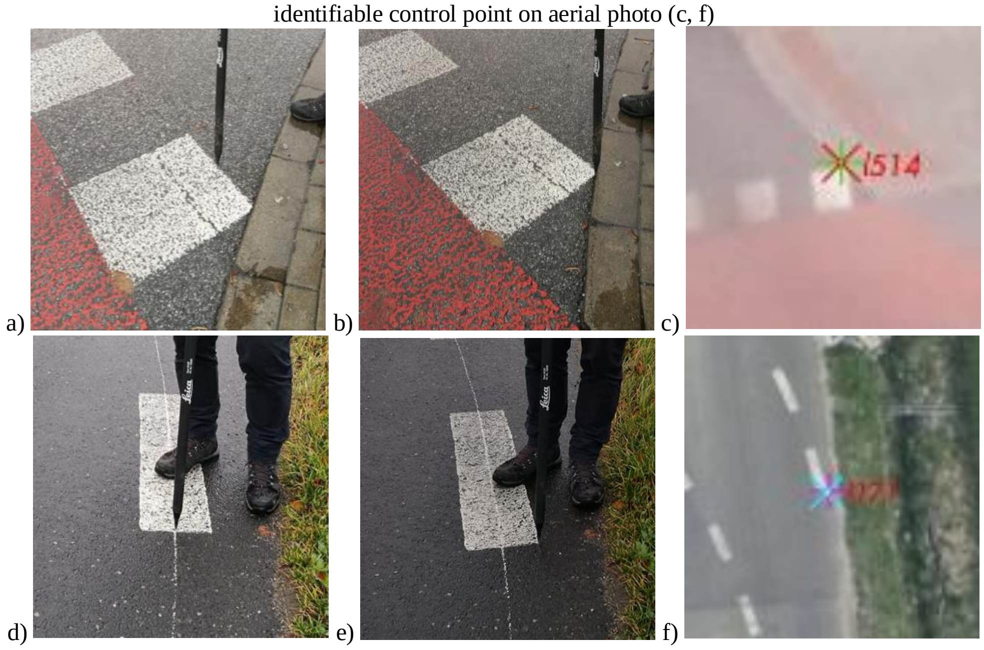
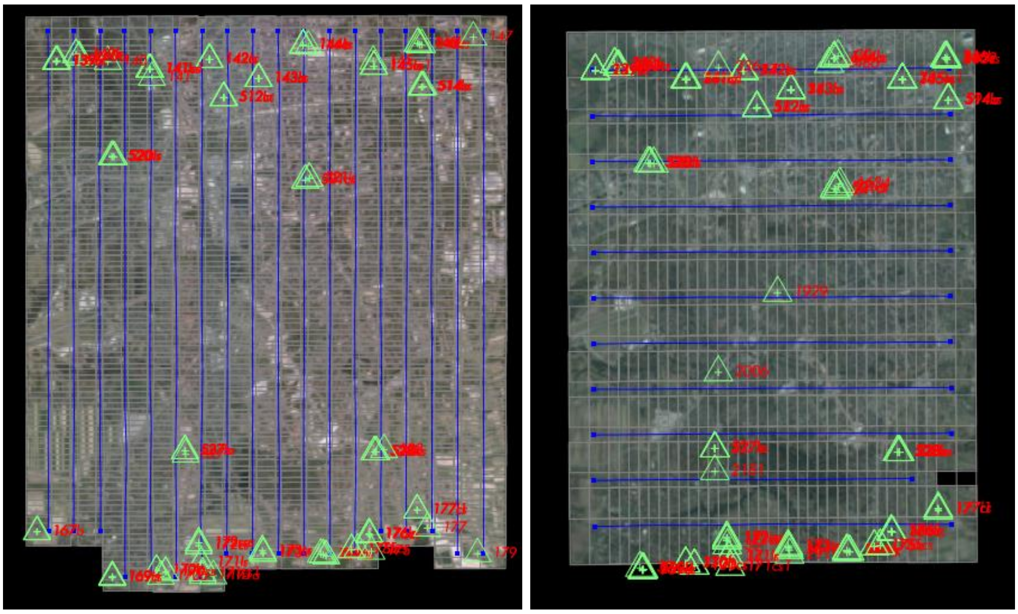


Figure 3. Examples of natural linear-type ground control points used in experiment variants: centre of linear-type object (option 1) (a, d), corner of linear-type (option 2) (b, e) and the view of these identifiable control point on aerial photo (c, f)

3. EXPERIMENT

In the experiment, 2 blocks of photos were developed, covering the same area of the southern part of Łódź, including the downtown (Figure 4):

- Block_1: images with resolution of GSD = 0.05 m, UltraCamXp camera, 843 images, 18 strips, north-south flight direction,
- Block_2: images with a resolution of GSD = 0.10 m, UltraCamXp camera, 209 images, 11 strips, east-west flight direction.



(a) (b)

Figure 3. View of photo sub-blocks used in the experiment: block_1 GSD=0.05 m (a), block_2 GSD=0.10 m (b)

In both cases, camera position in flight (GNSS technique) and angular orientation (INS technique) were measured. In block_1 (GSD = 0.05 m), 33 points were premarked, of which 26 were treated as ground control points (GCP), and 7 as check points (ChP). The distribution of ground control is illustrated in Figure 4. This was the basic (reference) option - option_0.

In close proximity to the control points, natural ("identifiable") points were selected and measured as previously described, constituting respectively of options 1, 2, 3 and 4 of the ground control options for adjustment. The location of all control points (premarked and natural) was measured using the GNSS technique.

In block_2 (GSD = 0.10 m), no premarked points were available (photos taken on a different date). Therefore, it was assumed that the control points of the reference option (option_0) will be natural points, independently measured. Other natural points (control points, option 1, 2, 3 and 4) were selected and measured in the same way as for Block_1 keeping the same group of ChP points from option_0 for this block. Analysed control points for block_1 and block_2 in options 1-4 were the same identified, natural points in order to have the opportunity to compare results and assess the influence of the type of natural points on the final results of aerial triangulation.

4. AEROTRIANGULATION RESULTS AND THEIR ANALYSIS

Both aerial triangulation blocks, each in five variants, were adjusted in Trimble Inpho software. The following observation accuracy (standard deviation - STD) was assumed: terrain control points measurement 0.05 m, camera position measurement 0.03 m, and angle measurement 0.003°. In the adjustment process, no additional parameters (so-called self-calibration) were used because of the camera metrics and drift and shift were not modelled for the camera position measurements. Synthetic adjustment results are illustrated in Table 1 and Table 2.

Table 1. Results of aerial triangulation for block_1, GSD = 0.05 m

	option_0	option_1	option_2	option_3	option_4
sigma naught [μm]	1.0 0.2 of pixel	1.0 0.2 of pixel	1.0 0.2 of pixel	1.0 0.2 of pixel	1.0 0.2 of pixel
RMS automatic [μm] x y	 0.7 0.8	 0.7 0.8	 0.7 0.8	 0.7 0.8	 0.7 0.8
RMS manual [μm] x y	 0.7 0.9	 0.9 1.1	 1.1 1.2	 0.9 1.4	 0.9 1.2
Number of GCP / ChP	 26 / 7	 24/ 32	 24/ 32	 24/ 32	 24/ 32
RMS GCP [m] X Y Z	 0.035 0.041 0.038	 0.056 0.068 0.043	 0.055 0.079 0.037	 0.033 0.071 0.045	 0.039 0.069 0.055
RMS ChP [m] X Y Z	 0.025 0.034 0.076	 0.035 0.043 0.066	 0.036 0.046 0.064	 0.038 0.046 0.065	 0.035 0.050 0.066
RMS GNSS [m] X Y Z	 0.021 0.020 0.014	 0.021 0.020 0.014	 0.021 0.020 0.014	 0.021 0.020 0.014	 0.021 0.020 0.014
RMS IMU [deg] omega phi kappa	 0.001 0.001 0.001	 0.001 0.001 0.001	 0.001 0.001 0.001	 0.001 0.001 0.001	 0.001 0.001 0.001

Table 2. Results of aerial triangulation for block_2, GSD = 0.10 m

	option_0	option_1	option_2	option_3	option_4
sigma naught [μm]	0.8 0.1 of pixel	0.8 0.1 of pixel	0.8 0.1 of pixel	0.8 0.1 of pixel	0.8 0.1 of pixel
RMS automatic [μm] x y	 0.7 0.6	 0.7 0.6	 0.7 0.6	 0.7 0.6	 0.7 0.6
RMS manual [μm] x y	2.1 1.4	1.0 1.1	1.2 1.2	1.3 1.4	1.3 1.2
Number of GCP / ChP	11 / 5	20 / 13	20 / 13	20 / 13	20 / 13
RMS GCP [m] X Y Z	 0.060 0.048 0.043	 0.054 0.045 0.028	 0.055 0.065 0.030	 0.097 0.047 0.027	 0.100 0.054 0.029
RMS ChP [m] X Y Z	 0.060 0.060 0.094	 0.052 0.083 0.159	 0.058 0.081 0.169	 0.055 0.085 0.166	 0.059 0.076 0.149
RMS GNSS [m] X Y Z	 0.034 0.024 0.015	 0.038 0.024 0.013	 0.039 0.024 0.014	 0.037 0.023 0.014	 0.037 0.023 0.014
RMS IMU [deg] omega phi kappa	 0.001 0.001 0.001	 0.001 0.001 0.001	 0.001 0.001 0.001	 0.001 0.001 0.001	 0.001 0.001 0.001

These tables contain RMS errors after adjustment. The individual columns relate to subsequent options of control points, and the lines contain accuracy assessment (RMS) after adjustment: sigma naught, error of automatic and manual measurement of image coordinates, number of points in the block (GCP and ChP), block fitting error on control points (GCP) and on check points (ChP), accuracy of camera position determination (GNSS technique) and its angles (INS technique).

Block 1 in all control point options has internal compatibility (sigma naught) at 1.0 μm level, which corresponds to 0.2 pixels. This is a very high accuracy, though achievable in production practice thanks to the quality of pictures taken with large-format digital cameras and automatic measurements of image coordinates (image matching technique).

Block fitting errors on control points (GCP) have a similar value for all options of the identified control points (at the level 0.03-0.08 m) and are only slightly larger than the option_0 – target control points (level 0.03-0.04 m). More reliable assessment of aerial triangulation is given by discrepancy at check points (ChP); horizontal accuracy is similar in all control point options, including option_0 and is 0.03-0.05 m and altitude accuracy is in the range of 0.06-0.07 m.

These discrepancies compared to the discrepancies on control points (GCP) practically coincide in terms of horizontal discrepancies and are slightly larger in terms of altitude discrepancies, which is in line with expectations.

From the point of view of the objective of this study, it should be emphasized that there is no visible decrease in aerial triangulation accuracy based on natural points or differences between the identified control point options. If such a difference were present, it should appear in the highest resolution photos, i.e. in block 1 (GSD = 0.05 m). The reliability of the above observation is reinforced by the fact that the assessment is based on a large number of check points.

Analysis of the results in block 2 (double the resolution of photos in block 1) generally leads to very similar observations as those in block_1. The internal cohesion of the blocks is even better (sigma naught = 0.8 μm), however the discrepancy at the check points is greater, especially height (2-2.5 times), but this is due to half the resolution. Looking at the results from the point of view of the research objective, no differences in accuracy between different control point options are found.

5. CONCLUSION

The conducted research clearly confirms that the development of aerial photographs can be based on field photogrammetric control constituting natural points identified in the terrain, such as the centres of covers, manholes or horizontal marking lines painted on roadways and parking lots. Aerial triangulation results based on different types of control points allow us to state that natural points are practically slightly inferior to the target points.

This application also concerns the development of high-resolution images, including the resolution of GSD = 0.05 m (and even smaller) - the highest used in photogrammetric practice. Images with high resolution (GSD = 0.05-0.10 m) are usually used for highly urbanized areas that are rich in detail for underground devices and numerous horizontal markings on roads and parking lots; there should be no trouble choosing and measuring natural control points in the photo block, however, in rural areas, despite the results achieved and presented in this paper, premarking of ground control points must be applied due to a lack of detail that can be used as a control or check points.

The automatic aerial triangulation of photos obtained with large-format digital cameras allows obtaining horizontal accuracy assessed at independent check points (ChP) at a level below one ground sampling distance of photos and an elevation accuracy at the level of 1.5 pixels. The above conclusion is of great practical significance as it allows the rather troublesome and time-consuming stage of field premarking of control points to be avoided. It can also be considered within the work of Regulation (2011) update.

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PROBLEMATYKA WYKORZYSTANIA POMIARÓW OSNOWY IDENTYFIKOWALNEJ NA WYSOKOROZDZIELCZYCH ZDJĘCIACH LOTNICZYCH

SŁOWA KLUCZOWE: aerotriangulacja, osnowa, sygnalizacja, identyfikacja

Streszczenie

Artykuł ukazuje wpływ doboru osnowy fotogrametrycznej w postaci punktów naturalnych zamiast sygnalizowanych na wynik aerotriangulacji obrazów lotniczych o wysokiej rozdzielczości o pikselu rozmiaru poniżej 10 cm. W eksperymencie testowano dobór fotopunktu jako obiektu punktowego, liniowego, pomiaru jego środka lub narożnika. Eksperyment pozwala udowodnić możliwość stosowania osnowy naturalnej zamiast sygnalizowanej, co znacznie zmniejsza koszty misji fotogrametrycznych w obszarach urbanizowanych, w których łatwo znaleźć jednoznacznie identyfikowalnej punkty naturalne, mogące posłużyć orientacji obrazów lotniczych. W eksperymencie wykorzystano 2 bloku zdjęć o GSD 5 i 10 cm, dla których wykorzystano pomiary tych samych 4 zestawów osnowy naturalnej porównując wynik z wariantem referencyjnym.

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