The potential accuracy of the survey of landform changes using archival orthophotos: case study of the Białka River valley

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Abstract. **The orthophotos were prepared from archival aerial photos of the Białka valley taken in 1977, 1981 and 1994. As a part of this process, ground control points were measured with use of a digital orthophotomap with EPSG 2180 georeference system and digital terrain models (DTM), georeferenced in the same way. The accuracy of measurements was verified during aerotriangulation of the photos. To improve the methodology of archival photos orhthorectification, analysis of the accuracy of control points was made, indicating that it depends on the scale, the age and quality of the archival photos and the location of control points. It was found that the control points localized on such objects as pole bases, crossroads (meant as point of crossing of centerlines of roads), corners of buildings and crossings of the borderlines of parcels, provide sufficient accuracy of aerotriangulation and an exterior orientation, due to their unambiguous identification on the archival aerial photos and physical stability over the whole period during which the photogrammetrical flights had been undertaken.**

I. INTRODUCTION

The orthorectification of irregular blocks of aerial photographs was conducted for the study of river channel changes in the Polish Carpathians based on archival cartographic and photogrammetric materials. The selected aerial photos were grouped in time horizons (air raids) from the years 1977–1994, covering the area of the Białka valley from the village of Jurgów to the river mouth to the Dunajec.

It was assumed that only horizontal variability of the river channels would be analyzed. The vertical changes shall be a subject of separate study. Preliminary analysis of the acquired archival photogrammetric materials led to the conclusion that the minimum terrain size of the resolvable detail is about 0.5-1 m and so is the potential accuracy of the surveys to be made on these materials. It was considered as sufficient in geomorphological studies of river channels. Therefore, in the orthorectification process of these materials, two sources of data were provided for gaining control points: a contemporary digital orthophotomap and digital terrain model, both providing sufficient accuracy for the study. As follows from previous experience, accuracy of field survey of control points with a GPS receiver is an order of magnitude greater than the precision of measurement of point location on photogrammetric material [1]. Otherwise, this method causes problems with proper identification of the control point. Proper selection and measurement of ground control points was the crucial issue for the accuracy of the orthorectification. The discussion of this operation with regard to archival aerial photos processing is the purpose of this paper. This work also aims to demonstrate that contemporary digital orthophotomap and DTM are the measuring material that is sufficient to obtain control points for the purpose of photogrammetric studies used in geomorphological research.

II. MATERIAL AND METHODS

The following aerial photos were acquired for the study:

1977 year - 8 pictures at approx. scale 1:20,000,

1981 year - 21 images at approx. scale 1:6000,

1994 year - 6 images at approx. scale 1:30,000.

The material for the survey of control points consisted of: digital orthophotomap of 2009 (pixel size of 0.25 m), Polish state reference system “1992” (EPSG 2180) and digital terrain model (DTM) of 2009 in the form of TIN (triangular irregular network, with linear interpolation of the planes), obtained using

In: Geomorphometry for Geosciences, Jasiewicz J., Zwoliński Zb., Mitasova H., Hengl T. (eds), 2015. Adam Mickiewicz University in Poznań - Institute of Geoecology and Geoinformation, International Society for Geomorphometry, Poznań

stereophotogrammetrical method, georeferenced as described above.

Measurement of the control points comprised:

– identification of the terrain object with suitable properties on orthophotomap and archival aerial image,

– measurement of its horizontal position on orthophotomap (planar coordinates in „1992" reference system) and its altitude on DTM referenced vertically to the geoid GRS 1980,

– measurement of the control point position in the pixel coordinate system of background aerial photo frame.

The remaining part of orthophoto processing methodology is consistent with the methods adopted in Polish state surveying services [2].

Because of the variability of local accuracy of orthophotomap and DTM, it was assumed that the number of control points should be 2-3 times greater than it is necessary to align and orthorectify the block of archival aerial photographs. The control points were measured in the groups of 2-3 points in close proximity. This method helps to maintain proper block alignment accuracy and to eliminate incorrectly measured control points, if necessary. Thus, the local and the average error of control point location (both horizontal and vertical) would be maintained in the previously assumed limits.

The control points were localized on:

– corners of buildings

– intersections of roads, understood as an intersection of their axes

– balk tripoints

– basis of the low voltage net and telephone net poles.

The main condition for each control point was its visibility on the overlapping aerial photographs in the block; another one was their unchanged location in the years 1977–2009. Figure 1 presents an example of a control point located on the basis of a low voltage net pole. In this case, the main condition of accurate location of the point is sun light direction and the presence of the shadow visible on the image of 1981 (Fig. 1A), and the orthophotomap of 2009 (Fig. 1B). Irregular shape of the aerial photo blocks made it difficult to meet these conditions. Therefore, 4 to 5 iterations of the control points selection and the alignment of block images were carried out for each archival aerial photo raid. The results of the survey and alignment were considered acceptable due to the accuracy of the block alignment criterion. It was assumed that an RMS error should be less than the theoretical accuracy of the measurement point on the digital orthophotomap with a pixel size of 0.25 m. According to the accepted standards of measurement accuracy, in this case it is equal to the triple size of a pixel, i.e. 0.75 m [3]. The second criterion is that the measurement deviation should not exceed the measurement accuracy of the source material at individual points. Depending on the results of the alignment, the control points with the highest error were eliminated. Where no good results were obtained with this method, in the next stage new control points were selected, if the former ones appeared to be situated on the objects that might have changed their position.

Figure 1. Example of location of a control point on the low voltage pole basis; A – aerial photo of 1981, B – orthophotomap of 2009.

III. RESULTS AND CONCLUSIONS

The number of control points measured for each air raid was:
year 1977: 20 control points
year 1981: 18 control points
year 1994: 14 control points.
Subsequently, an aerotriangulation and the alignment of the aerial photo blocks were performed. The results of this operation for each of the air raids were as follows:
year 1977 – 1 point rejected, 19 used, the average RMS error: x

0.176 m, y 0.153 m, z 0.139 m;
year 1981 – 1 point rejected, 17 used, the average RMS error: x 0.071 m, y 0.062 m, z 0.048 m;
year 1994 – all the 14 points used, the average RMS error: x 0.009 m, y 0.011 m, z 0.007 m.

The value of residuals at individual control points ranges from 0.01 to 0.5 m (Fig. 2). Most of residuals for individual control points is less than 0.4 m; the largest values are for the 1977 air raid (marked as "77") and the smallest ones for the air raid from 1994 (marked as "94"). It implies that measurement errors were small enough to allow the performance of aerial triangulation of the photos with the previously assumed accuracy. The vertical residuals range from 0.01 to 0.28 m (Fig. 3), and as previously described, ,the largest values of horizontal residuals were found for the 1977 air raid, and the smallest for the 1994 air raid (described as "77", and "94" in Fig. 2), that determines the potential exactness of the stereo digitization accuracy. All these values are less than the previously accepted value of acceptable measurement error. The results of aerotriangulation and the alignment affected the exactness of orthorectification of the images. An average error of translation was less than 0.79 m. Most frequently, in the case of aerial photos of 1977 and 1981, the error was in the range of 0.2-0.3 m; the largest individual values of the error were found for the vertical coordinate in the photo from 1994 raid.

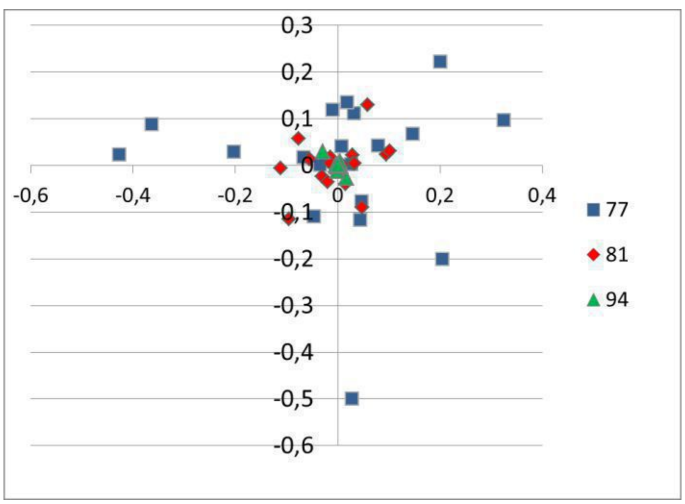

Figure 2. Horizontal dispersion of the residuals of the control points for each air raid. X and Y axis scaled in metres.

The errors were caused by radiometric non-uniformity of the material (photos taken at different parts of the day and at different light), that resulted in the improper identification of the tie points on individual photos. In this case, accurate measurement and alignment of control points allowed to identify and eliminate the tie points with the largest errors.

A strong relationship between the value of the observed error and the age of aerial photos was found. This can be explained by the photographic material distortion that could have occurred during its storage, before scanning, what affected the accuracy of the interior orientation and, consequently, the accuracy of aerotriangulation. Another important factor was the radiometric quality of the material: the best, but not uniform, for the pictures of 1994, significantly worse for those of 1977 and the worst for the images of 1981. In the case of images of 1994, it caused errors at the tie points, described above. In the remaining cases, it made the precise location of control points difficult, which led to a lower accuracy of aerotriangulation.

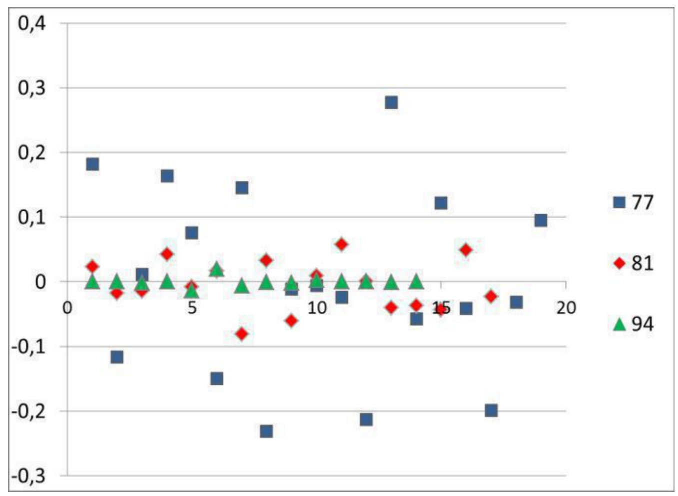

Figure 3. Vertical dispersion of the control points residuals; X axis presents number of the control point, Y axis scaled in metres.

Satisfactory results of aerotriangulation constitute the basic condition for exact measurements of the landform change on the orthophotomap, as well as in three-dimensional technique. They have been the result of careful selection and location of the control points; however, the rejection of some of them was necessary, in a situation where the deviation of measurements at a given point considerably exceeded the acceptable range. Apart from the aforementioned factors, other ones also had an impact on the quality of orthorectification: the changes of the shape of the objects, which were used to locate the control points, and the landform changes, mainly vertical, of the terrain where control points were located. The last mentioned issue, especially if meant to be studied with use of photogrammetrical methods (digitization on the stereopair of archival aerial photos), is so far insufficiently recognized in Poland. The improvement of the methods of orthorectification of the archival aerial photos gives an opportunity to expand the research in this area.

ACKNOWLEDGMENT

This study was performed within the scope of the Research Project DEC-2013/09/B/ST10/00056 financed by the National Science Centre of Poland.

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