HISTORICAL ORTHOPHOTOS CREATED ON BASE OF SINGLE PHOTOS - SPECIFICS OF PROCESSING

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ABSTRACT

This article focuses on problematics of creating digital orthophotos using historical aerial photos. The project is part of a grant project that deals with change in rural architecture over the last two centuries. The orthophotos are one of the outputs created in the grant project and illustratively represent development of the selected villages over the last 80 years. In addition to orthophotos other outputs such as analytical map data (development of selected villages since the years around 1830 till present) are created. The article describes the current state of orthophoto creation and also difficulties that might be encountered at processing of historical photos. The specificity of this project is in small areas (primarily built-up areas of selected villages) that are processed. Such an area is usually captured only in one or two photos, which significantly affects the way of the photogrammetric processing. The project involves three preselected villages. Orthophotos are created for each of them in three terms (approximately 1938 + 1970 + 1985) and this chronological order is amended with purchased data for the year 1953 and the present. The time series of orthophotos, together with other inputs, bring better understanding to the development of rural settlements in the context of socio-historical events – e.g. Second World War, socialist expropriation, collectivization, agricultural large-scale production, changes in ownership after 1989 etc.

KEYWORDS

Historical aerial photo, Historical orthophoto, Photogrammetric technologies, Rural transformations, Multitemporal analysis

INTRODUCTION

Orthophotos have been a major product of aerial photogrammetry for many years and they are widely used not only in GIS applications. The speed of their processing and the quality of the outputs have increased with the arrival of digital cameras, as well as the availability of orthophotos capturing the most current state of a particular area.

Historical aerial photos - sources

In addition to current image data, historical aerial photos (HAP) can also be used for various purposes. In the former Czechoslovakia, the systematic aerial photography began in 1935 on the territory of Slovakia, as Nociarová mentions in [1]. The HAP for the Czech Republic has been managed by the Military Geographic and Hydrometeorological Authority (in Czech: Vojenský geografický a hydrometeorologický úřad - VGHMUr) in Dobruška. Their archive contains about

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900,000 photos which have been stored since 1936, as reported by Stehlík [2]. The gradual digitization of the archive is currently being carried out in cooperation of the VGHMUr and the Land Survey Office. For viewing, searching for HAP information and ordering, an application Archive of aerial survey photos (in Czech: Archiv leteckých měřických snímků) is available at [3].

This archive is a main source of HAP in the Czech territory. Photos from foreign archives are used only in extraordinary cases. An example of that are archive military reconnaissance aerial photos of Prague taken at the end of the Second World War. With accessing and using these photos for various purposes deals e.g. [4].

The development of aerial photography for reconnaissance purposes, which occurred during the First World War, certainly had an impact in our country. However, the oldest currently known report on aerial photography for measuring purposes is related to the year 1927. At that time the Technical Squadron was established at the 2nd Aviation Regiment in Olomouc and within it the Photographic Section, as stated by Prokeš [5] and Fidler [6]. Former Military Geographic Institute had permanently available one airplane and a trained pilot for aerial photography since 1927, supplemented in 1929 with the equipment for serial photography, as mentioned by Jalůvka [7]. In the spring 1927, a photogrammetric aerial photography of Adamov forestry farm was carried out for the University of Forestry in Brno. This set of photos was retained and recently was processed into an orthophoto by Skoupý [8]. Another valuable ensemble was purchased in that year for the Olomouc municipality by the same provider. These photos were transformed in the form of photoplan by Prokeš [5]. The first documented aerial photography of several archaeological sites dates back to 1929, see Böhm [9]. However, except of the above mentioned valuable findings, most of photos of an older date are difficult to trace, precisely data on them have not been stored in the archive of VGHMUr.

Historical orthophotos and HAP - utilization

The historical orthophotos can be used in many areas. In most of the works mentioned below, they are brought into context with other map and image resources. Thus they form one of the layers of multitemporal analysis.

Observation of landscape changes is one of the areas where historical photos and outputs created from them are applied. Applications in forest management are reported by Skoupý [8] - who describes a creation of thematic forest maps. Other examples are mentioned by Nociarová [1] - she deals, among others, with the issue of property restitution of forest grounds and by Kardoš [10] - who also describes a creation of relevant resources for complex land consolidation projects. With issues in the monitoring of development of the landscape structure in particular cadastral districts deals Jiskrová [11] and a similar topic in a larger territory has been solved by Prchalová [12].

An example of the use of historical photos in geographic research is the work of Chmelová [13], who deals with changes in land use in a given territory, and Stoupa [14] solves also a similar theme.

In built-up areas, historical orthophotos can be used, for example, to explore urban development from various perspectives. This issue is addressed, e.g. by Sádovská [15] in Olomouc city, she uses also the above mentioned HAP from 1927. Most of the large cities in the Czech Republic also publish historical orthophotos from several time periods on their public map servers. The institute of urban planning and development of Prague, among other documents, has published foreign HAP by 1945 (mentioned above) within the project of Two Pragues [16].

Archaeology is another area where HAP finds its use. Šmejda [17] deals with such applicability, for example. An interesting application is also the use of HAP in mapping of poorly

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documented drainages constructed in the past, see Šafář [18]. A project that is in scope of the environmental protection was introduced by the Czech Environmental Information Agency [19]. The historical orthophoto of the entire Czech Republic has been created as a basis for the inventory of contaminated sites (orthophoto CENIA – photos primarily from year 1953). For more information about this project see Sukup [20]. The topic of searching for old ecological burdens or localization of unexploded war ammunition using HAP is reported in foreign resources e.g. in [4].

The use of historical aerial photos as one of the resources for exploration and design works is also recommended by methodical publications such as [21], [22] and [23]. Surely we can find other areas where this type of image data finds its use. The user community is also constantly expanding with an improving availability of the image data.

Rural transformations – project objectives

The historical orthophotos are used together with other documents in our project for an art-historical research of the urban development of selected villages. One of the project objectives is to point out neglected historical and art values of rural architecture. These values are often not taken into account when planning urban development. Thirty-nine smaller villages, which are far from the main interest of historical-urban research, have been chosen for the project. These villages are homogeneously distributed throughout the Czech Republic.

Village development analyses are based, besides the historical orthophotos, mainly on the analytical map data (maps of urban changes) and also on 3D digital models and simplified ground plans of rural architecture. The art-historical assessment has been carried out for the whole set of selected villages. However maps and models are created for a third of them only and finally just three villages have been selected for the creation of historical orthophotos. For these villages two orthophotos has already existed - current and historical (see CENIA). Our task was to create three more orthophotos approximately for periods around years: 1938 + 1970 + 1985, with the main emphasis on a built-up area of the villages, and required orthophoto accuracy within 3 m.

The next part of the article deals with creation of historical orthophotos. The data used, the technological process and the achieved outputs are described in more detail. Attention is also paid to the specifics of the approach we used and the difficulties we encountered. It needs to be emphasized that the described project is still in process and also other ways to improve the project outputs will be sought after.

METHODS

Although the general procedure of photogrammetric processing of HAP is more or less standardized, the specific process of a particular project is always strongly influenced by a number of factors. These include e.g. – the quality and number of photos and a knowledge of calibration data; size of the area to be processed and a possibility of finding suitable ground control points in them; the availability of the digital terrain model etc. Features of the processing software need to be mentioned, too. Possible variants of the technological process of a historical orthophoto creation in the context of the input conditions are summarized, for example, by Šafář [18].

Various authors choose a variety of ways of the photogrammetric processing according to the type of assignment, the parameters of required outputs and their technical equipment. In some cases, HAP is used directly, i.e. the HAP is interpreted without further processing. This is used in archaeological applications see Šmejda [17], for example. Simplified processing of HAP into photoplanes using various types of planar geometric transformations is also quite common. This procedure was used by Prokeš [5] or Dědková who took advantage of affine transformation [24].

Sádovská and Stoupa used polynomial transformations of various degrees, see [15], [14]. However, the outputs obtained in these ways have limited geometrical accuracy only (i.e. dozens of meters), as the authors report in their projects. The goal of our project is to obtain outputs with much higher precision. The subsequent text deals with this topic.

Processed territories - basic characteristics

Detailed analysis of the processed area for the photogrammetric processing of HAP is not necessary. However, it is usually advisable to be familiar with its basic parameters. Three selected villages - Hostouň u Prahy (pilot project), Ropice and Držkov have been gradually processed in the project. The basic characteristics of the mentioned villages, which influence the processing, are summarized in Table 1.

Tab. 1 - Processed territories - basic characteristics

village	Hostouň	Ropice	Držkov
region	Central Bohemia	Moravian-Silesian	Liberec
acreage of Cadastral District - CD [km2]	10,3	10,1	5,9
average altitude [m]	341	310	597
type of relief	flattened	slightly wavy	wavy
distribution of forest land in CD [%] *	up to 5	up to 20	up to 50
building structure	constricted	diffused	constricted
number of houses **	471	488	260
developement of build up area 1938-2018	dynamic	gradual	little
urban area in CD [%] *	up to 20	up to 60	up to 20
* author's estimate based on orthophoto 2018			
** data source - Registry of census circuits and buildings .. http://apl.czso.cz/irso4 .. validity to 5.9. 2018			

Regarding the used technology of processing, the following parameters are of particular importance - the type of the terrain relief, the afforestation of the area, the extent of the built-up area and its development in the monitored periods. The first one is related to the knowledge of the elements of interior orientation (mainly the lens distortion) and the other mentioned are foremost related to the availability of sufficient number of appropriately positioned ground control points.

Input data

The following input data were acquired in order to elaborate our project of creating historical orthophotos of the selected villages in three time periods: HAP, current digital terrain model, current cadastral map, current orthophoto and historical orthophoto CENIA.

Historical aerial photos

Key data for further processing are HAP from the archive of VGHMUr. These photos were selected within an application [3]. The pilot part of the project was the processing of the village of Hostouň, where stereo pairs were ordered from the archive for testing of the technological process. Regarding the results obtained (see below), the demand for stereo pairs was not further applied. Altogether fourteen photos were finally ordered and their basic parameters are reported in Table 2.

Tab. 2 - Historical aerial photos - basic parameters

village	YOR	NOI	f [mm]	FS [cm]	h [km]	S	DAOV [°]	NFM
Hostouň	1938	2	211,59	18 x 18	4,2	19 900	52,6	4
	1969	2*	115,21	18 x 18	3,2	24 500	94,8	4
	1983	1	151,99	23 x 23	2,8	18 300	92,1	4
Ropice	1937	2	211,31	18 X 18	4,3	20 500	53,2	4
	1972	2	114,36	18 x 18	2,7	23 400	90,7	4
	1986	2*	152,00	23 x 23	4,5	29 600	90,2	4
Držkov	1938	1	211,09	18 x 18	4,2	19 700	59,0	4
	1971	1	209,87	18 x 18	2,9	13 700	57,6	4
	1988	1	152,27	23 x 23	2,1	13 700	91,0	8
legend:	**YOR** - year of recording; **NOI** - number of photos; **f** - focal length; **FS** - frame size; **h** - flight height; **S** - scale;							
	DAOV - diagonal angle of view; **NFM** - number od fiducial marks							
	* used only one of them							

Following values were known for photos - the focal length (shown in the photo) and the scan resolution value (VGHMUr denotes 14/15 μm). Other values were derived also from the knowledge of the extent of the area displayed on particular HAP, see Figure 1. The values show relatively large variability of the used scales and the use of cameras with normal and wide-angle lenses.
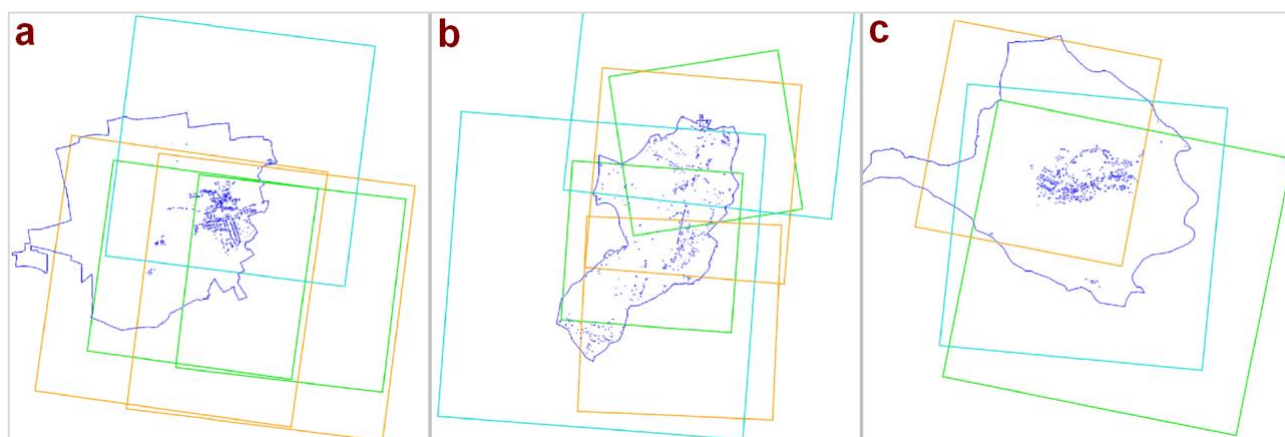

Fig. 1 – Covering of cadastral districts by HAP – a)Hostouň, b)Ropice, c)Držkov.
Years – green = 1938+37+38, orange = 1969+72+71, blue = 1983+86+88

Digital terrain model and map data

The digital terrain model (DTM) is an essential resource for creation of an orthophoto. The specificity of HAP processing is in the fact that the model should relate to the historical state of the area. Most authors, such as Šafář [18] and Sukup [20], state that one of the ways to deal with this is to use the current DTM as a basis and provide its local editing. In case of its locally non-updated areas for a given timeframe, they recommend to use the HAP and edit DTM, by using stereoplotting, for example. The extent of possible mismatches depends, among other things, on the size of the territory and the way of its development since the acquisition of HAP, which can be determined from various sources.

In our project we process three relatively small cadastral districts, where large changes are not expected. In the pilot project Hostouň (1969) stereo pairs of photos were acquired for purposes of testing. We wanted to verify the possibility of using HAP for automated DTM creation by image correlation method. The progress and results in our case have shown that DTM in satisfactory quality cannot be expected, see below. That is why the digital terrain model based on the data of aerial laser scanning - DMR 5G was purchased from the Land Survey Office.

The current orthophoto, the historical ortophoto CENIA and the current cadastral map are other resources available to all localities. This type of resources is mainly used to find suitable ground control points for orthophoto and to verify the accuracy of the results.

Processing – image orientation

The process of image orientation is always influenced by the number of the photos, by their layout and also by our knowledge of their parameters. In our case, we worked with single photos only, where the elements of interior orientation were not known. We used the PhoTopoL Digital Photogrammetry Workstation v.9 and 9.5 for photogrammetric processing.

Interior orientation

A calibration protocol, which contains all the essential information for the photogrammetric processing, is usually not available for historical photos. Therefore, the elements of interior orientation (IO) are to be determined in another way.

The approximate value of the focal length can be determined directly on the HAP, where it is part of the frame data. If scanning resolution is known, then it is also possible to determine the actual dimensions of the photo at the time of scanning and image coordinates of the fiducial marks (FM). In our case four fiducial marks were designated on all photos. Their pixel coordinates were deducted twice from the digital image, and the real values in mm were acquired from the average values using resolution knowledge. For the purposes of comparison, the coordinates were transformed by the congruent transformation so that the origin is in the centre of the image and the x-axis in the horizontal link of FM. Other elements of IO (the position of the principal point + the course of distortion) could not be easily detected at that moment.

It is commonly reported that unknown IO values can be determined by using the bundle block adjustment, with knowledge of at least approximate values, see Šafář [18], Prchalová [12] at al. However, this procedure can only be used if we process multiple photos, which is not the case of our project. Other authors neglect image distortion and principal point shift, see Skoupý [8], which certainly affects the accuracy of the outputs. It depends on the required accuracy, the type (plane / rugged) and size of the area, the type of lens used (angle of view vs. distortion), etc. whether the outputs will be still suitable for use (see also Table 3).

With regard to the technical and time conditions (e.g. the need to produce at least preliminary outputs), a simplified solution was chosen for the current stage of our project. The focal length and the FM image coordinates were considered only. Finding suitable process and technical solution for acquiring other elements of IO is priority topic for the second part of project works.

Exterior orientation

Ground control points (GCP) are of a key significance in calculation of elements of exterior orientation of HAP. Their optimal number and spacing is determined by the calculation method (block of photos vs. a single photo). Considering GCP are primarily sought out on historical photos, their image quality is of a great importance. This quality, as shown in Figure 2, can be very variable. It is not a rule that photos of older data are of lower quality.

Fig. 2 – Image quality of HAP – Ropice village (selected part of photos)
Historical aerial photos © VGHMUr
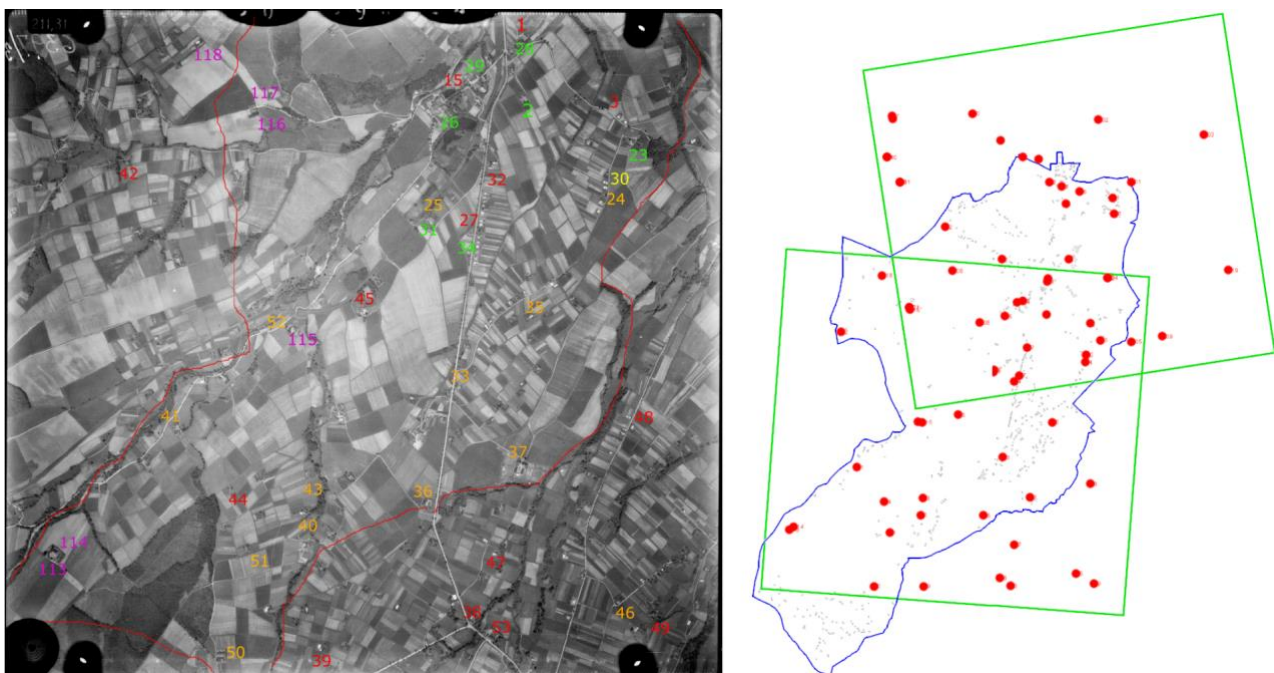
Fig. 3 – Distribution of GCP – layout (left) and scheme (right), Ropice village – 1937
Historical aerial photos © VGHMUr

When searching for GCP, all of the above mentioned map resources were used as a reference. Our goal was to cover the particular photos homogeneously if possible with sufficient density, also in context of the next calculation of other unknown IO. When selecting the points, special emphasis was placed on covering the urban areas of the villages, because they are in our focus primarily. Natural points were selected (corners of buildings, crossing roads, etc.). In some cases, identifying the same point on particular photos was very difficult. This was especially true in areas with more significant changes – e.g. a continuous new building development or in the forest or fields areas. The coordinates of the GCP were determined primarily from the cadastral map and the current orthophoto. In case of small number of the ancillary points orthophoto CENIA was also used. Thus differences in coordinates (acquired from various resources) were obtained for each point. These differences, together with information of point identification, indicate credibility of the point, which was color-coded in our sketch. A set of 20-30 points was obtained in this way for each photo, see Figure 3. The heights of all points were acquired using the purchased digital model, see also the Hypsography Analysis application [25].
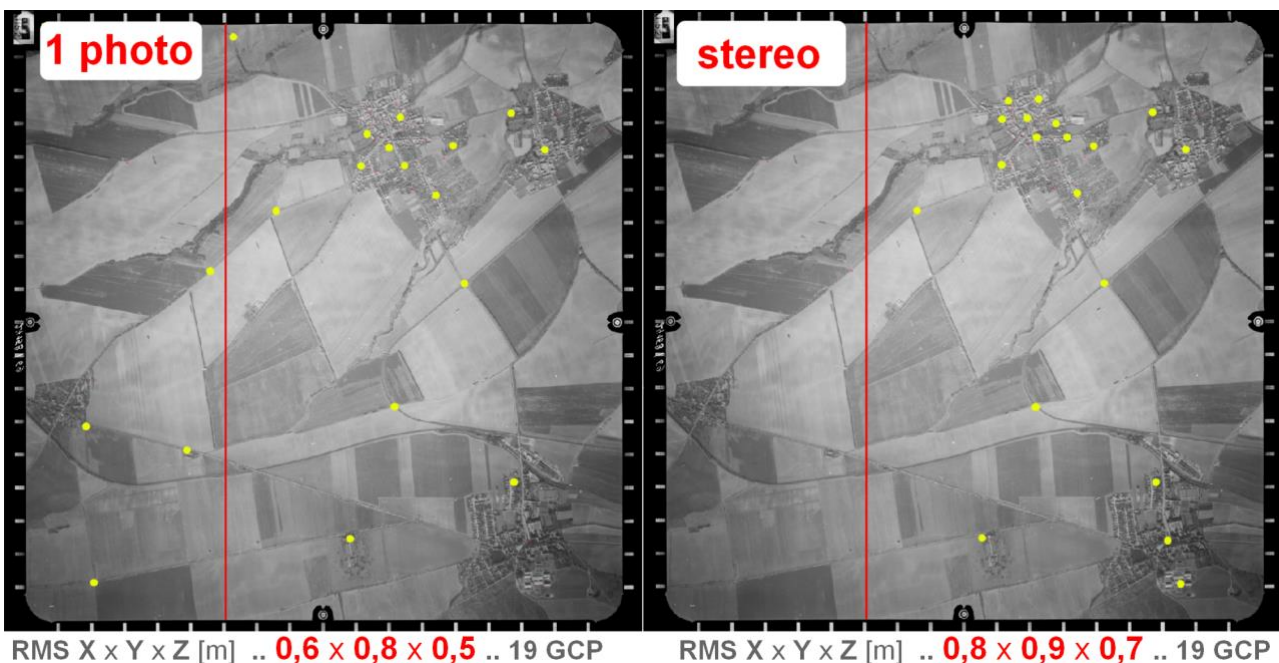

Fig. 4 – Distribution of GCP and EO precision, Hostouň village – 1969
Historical aerial photos © VGHMUr

In the pilot part of the project a suitable procedure for calculating the elements of exterior orientation of photos (EO) has been sought out. Photos from the Hostouň village acquired in 1969 were processed. The calculation of EO for both stereo pair and single photo was tested. To calculate EO and unknown IO values AeroSYS computing system was planned to be utilized, however this intention has not been fulfilled. The calculation failed - the results achieved even after a number of experiments did not match with the assumptions and the source of the problem has not been detected. It is possible that in our case there was a hidden incompatibility between the two used computing systems in terms of import / export of data or other defect difficult to detect. Thus, the calculation of EO has been performed in the PhoTopoL system, which in our version did not allow us to determine unknown IO values. Figure 4 illustrates an example of the resulting GCP layout for EO calculations for both test cases and achieved accuracy of the calculation. In total,

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eleven variants of the GCP layout have been verified, with an emphasis on a particular parameter – e.g. homogeneous distribution, emphasised build-up area, the build-up area only, etc.

Interpretation of the results achieved should be treated with certain circumspection. As indicated in results at Držkov village, see Table 3, the results may be of lower quality under other conditions. The calculation also showed an unexplained instability when changing some adjustable parameters - for example prior GCP accuracy. On the other hand, it has to be mentioned that verification of the accuracy of the outputs within the pilot project yielded in results that fulfilled the original assignment, see below. In the light of the lessons learned, the simpler way of processing was chosen for other locations. Only one photo with homogeneous coverage of points was used, also in context of the results obtained in the DTM creation, which is described below.

Tab. 3 - Exterior orientation – summary of results

	rms X [m]	rms Y [m]	rms Z [m]	MDZ [m]	IQ	S	DAOV [°]
Ropice							
1937_PH2	0,5	**0,5**	0,3		good	20 500	53
1972_PH2	0,5	**0,6**	0,5	100	weak	23 400	91
1986_PH1	0,7	**0,9**	0,8		very good	29 600	91
Držkov							
1938_PH1	1,0	**1,7**	0,7		very good	19 700	59
1971_PH1	**1,8**	1,4	0,8	150	very good	13 700	58
1988_PH1	1,9	**3,5**	2,0		very good	13 700	91
Hostouň							
1969_PH1	0,6	**0,8**	0,4	50	good	24 500	95
legend:	**1937_PH2** - year of recording + photo number; **S** - scale; **DAOV** - diagonal angle of view; **MDZ** - maximum difference of Z coordinate of used GCP; **IQ** - image quality						
initial assumptions:	- distribution of GCP is equable on each used HAP						
	- one typical result of EO is presented for each year						
	- number of used GCP is 15-25 per photo						

The issue of fine-tuning the EO calculation is not completely closed in our project. Some questions remain opened and search for relevant answers and procedures is currently being performed.

Processing - testing of DTM creation

The pilot project also tested possibility of obtaining a historical DTM directly on the basis of HAP. The stereo pair from 1969 with quite good image quality was used. The DTM was created with the automated image correlation method in the PhoTopoL system and the objective of testing was to find appropriate parameters of model creation. In this way, a number of model variants have been gradually created. Their common feature was a relatively high amount of incorrectly determined points. This reduced accuracy of output can be attributed to various influences. The nature of the territory (primarily built-up area) and limited image quality of the HAP belonged to the important ones. Achieving usable results required a large amount of manual editing – i.e. operator intervention. The factual result of the test was a model, which served as a basis for creation of one of the orthophoto variants. The accuracy of this output is shown in Table 4.

Based on the testing, the plan to use HAP for automated DTM creation was rejected. Reasons which had led to this were: large error rate of the automated processing, the need for

extensive operator intervention and variability of HAP quality, see Figure 2. The purchased DTM was used for the further processing of the orthophoto in the project. Possible local deformations due to its out-of-date nature would be in accordance with the recommendations of other authors, see above, solved individually by using of a stereoplotting of HAP, for example. However, this case has not occurred in our project yet.

Processing - orthophoto creation

The orthophoto has been created in three variants for the pilot project. These variants vary by - EO result used (one photo vs. stereo pair) and also by the type of DTM used (created in the project vs. purchased). The combination of EO from a single photo and the purchased DTM was used for the other projects based on the results of testing in the pilot project.
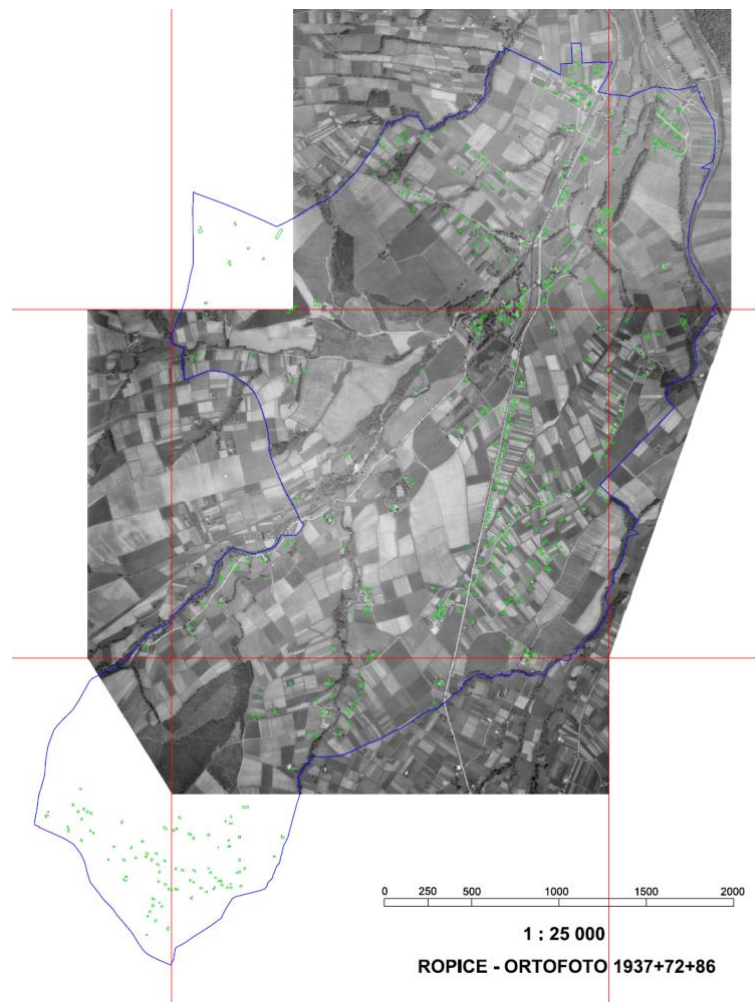

Fig. 5 – Ropice village – orthophoto 1937

Orthophoto creation was performed in a standard way. In case of more photos to choose from, the image quality was the key criterion. With regard to the size of the areas of interest and their coverage by HAP, see Figure 1, two neighbouring photos have to be used only at Ropice. Masking (manual mode) and mosaic operations were performed at two time levels (1937+72) in this case. The overlap of photos was not large, and achieved accuracy of matching corresponded to our expectations. Tie area of photos took place in rural areas and the dissonance there reached

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up to several meters (about 5 m). This inaccuracy can be explained, among other things, that the tie areas were mainly at the edges of the photos, where the influence of the neglecting of the distortion of the photos is the most obvious. This is another reason for seeking a suitable procedure for finding out all unknown IO, see above.

The resulting orthophoto was parted into 1: 5000 scale map sheets at the end of the processing and cartographic outputs were created, as reported in Figure 5.

Accuracy verification

Within the framework of the pilot project, a quality verification of the orthophotos (the three variants mentioned above) was performed. There were two types of the verification.

The first type was a visual verification at exposed sites of the area (both in the built-up area and in the rural area). Current orthophoto served as a reference. There were no significant inconsistencies in both types of data found in this type of verification. This shows, among other things, that there were no major changes in the terrain in the given territory during the reference period (i.e. 1969-2017). The set of images capturing tie areas was the result of the verification, see Figure 6 on the left. A similar type of verification was carried out in all other projects, and the results were generally analogical. A significant mismatch was not detected in built-up areas by this way. Slightly worse results have shown up in several rural areas, which may be attributed to above mentioned simplification in processing.

Fig. 6 - Verification of accuracy - visual in urban area (left) and CP distribution (right)
Hostouň village – 1969

The use of control points (CP) was the second type of verification. These points were sought out only in a built-up area of a village. The points were easy to identify in both types of data – i.e. on the 1969 orthophoto and the reference orthophoto 2017. Placement of the CP depicts Figure 6 on the right. The CP coordinates were obtained by using these two types of resources. The results of comparison of coordinates are summarized in Table 4. The table shows that the maximal differences in variants using the purchased DTM are almost identical. The maximal differences, in the variant using the DTM created, are twice higher. This finding is consistent with the assumption, that the quality of the purchased DTM is more homogeneous. Noteworthy values of average differences are at the third project. The systematic effect has occurred at the most in the case of single photo variant. Although all variants match the original requirements for

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orthophoto accuracy, they show possible future directions of our project development - dealing with systematic influences, for example.

We plan a more detailed accuracy analysis of all outputs with a larger CP set after modifying the technological process (including the exact determination of unknown IO values and the stabilization of the EO calculation).

Tab. 4 - Verification of accuracy – with use of CP

method	1 photo		stereo v1		stereo v2	
CPN	ΔY [m]	ΔX [m]	ΔY [m]	ΔX [m]	ΔY [m]	ΔX [m]
1	-1,30	-0,58	-0,48	-0,31	*4,12*	-1,18
2	-0,08	-0,40	-0,51	-0,23	-0,36	1,03
3	1,52	-1,75	-0,55	*2,17*	0,35	0,53
4	0,84	1,34	0,56	1,99	0,01	*3,45*
5	*2,23*	-0,65	*2,08*	0,23	1,82	0,55
6	-0,02	*-2,28*	0,38	-0,67	-1,13	-2,68
7	-0,01	-0,84	-0,14	-0,07	-0,70	0,38
8	0,35	-1,51	-0,03	-0,98	-1,12	-1,29
9	-0,63	-0,04	-0,88	0,11	-1,21	0,69
10	1,74	-0,69	1,80	0,43	-0,01	-2,17
∅	**0,46**	**-0,74**	**0,22**	**0,27**	**0,18**	**-0,07**

legend: **CPN** - control point number

1 photo - exterior ori. calculated on base of 1 photo only

stereo v1 - exterior ori. calculated on base of stereo + purchased DMR

stereo v2 - exterior ori. calculated on base of stereo + DMR created by us

CONCLUSION

The article describes the process of creating orthophotos on the basis of HAP. This type of output data will, together with other data, serve for assessment of the cultural - historical aspects of the transformation and development of rural architecture over the past two centuries. Historical orthophotos have been created for three selected villages at three time levels.

The technology used for orthophotos is quite standard. The main specificity of the project is that the areas of interest are of a small size (built-up areas of selected villages) and therefore only a single HAP was used for processing. Therefore, in context of the recommendations of various authors mentioned above, the bundle block adjustment method could not be used to calculate the unknown IO and EO values. With regard to the organizational progress of the project, the simplified version of outputs creation was used in the first half of the project. The missing elements of interior orientation have been neglected. Even such a procedure is consistent with the examples cited in the literature, see above.

A pilot project was performed. The use of HAP for automated DTM production was tested. Testing of various EO calculations was done too. On the basis of knowledge learnt in the pilot project, only a single photo (not a stereo pair) was used for the calculation of EO in the other projects and only the purchased DTM was used because of an excessive elaborateness when creating own DTM from HAP. The quality of the pilot project outputs has been verified in two procedures. The results obtained match with our expectations and intensions how the output data

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will be utilized. The results of the calculations and the accuracy verification also correspond to the values mentioned in the literature, see for example Šafář [18].

In the second half of the project, we will address issues that have gradually emerged during the processing. First of all - finding the right process and tools for detecting unknown IO, if we only process single photo, will be done. We will deal with certain instability of EO calculation when changing the parameters of the calculation also. Finally, greater attention will be paid to verifying of the accuracy of all outputs by using a larger set of CP to detect possible systematic errors. Our ultimate objective is, besides the further improvement of the outputs, the completion and stabilization of the used technology. It is important to emphasize that our outputs even in the current form are already well usable for cultural - historical research.

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