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APPLICATION OF TECHNICAL MEASURES AND SOFTWARE IN CONSTRUCTING PHOTOREALISTIC 3D MODELS OF HISTORICAL BUILDING USING GROUND-BASED AND AERIAL (UAV) DIGITAL IMAGES

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Abstract

Preparing digital documentation of historical buildings is a form of protecting cultural heritage. Recently there have been several intensive studies using non-metric digital images to construct realistic 3D models of historical buildings. Increasingly often, non-metric digital images are obtained with unmanned aerial vehicles (UAV). Technologies and methods of UAV flights are quite different from traditional photogrammetric approaches. The lack of technical guidelines for using drones inhibits the process of implementing new methods of data acquisition.

This paper presents the results of experiments in the use of digital images in the construction of photo-realistic 3D model of a historical building (Raphaelsohns' Sawmill in Olsztyn). The aim of the study at the first stage was to determine the meteorological and technical conditions for the acquisition of aerial and ground-based photographs. At the next stage, the technology of 3D modelling was developed using only ground-based or only aerial non-metric digital images. At the last stage of the study, an experiment was conducted to assess the possibility of 3D modelling with the comprehensive use of aerial (UAV) and ground-based digital photographs in terms of their labour intensity and precision of development. Data integration and automatic photo-realistic 3D construction of the models was done with Pix4Dmapper and Agisoft PhotoScan software

Analyses have shown that when certain parameters established in an experiment are kept, the process of developing the stock-taking documentation for a historical building moves from the standards of analogue to digital technology with considerably reduced cost.

Keywords: *3D modelling, digital image, UAV, Pix4Dmapper, Agisoft PhotoScan*

1. Introduction

Nowadays 3D data are a critical component to permanently record the form of important objects and sites. Virtualisation of historical buildings is the foundation for various measures aimed at protecting national heritage, such as documentation, digital preservation and conservation, monitoring, simulation of aging and deterioration, web-based geographic systems, virtual tours, multimedia museum exhibitions and so on (Remondino, 2011; Bruno et al., 2010).

All of these measures require pre-generation of a 3D model of a selected building. Automatic acquisition of a 3D model from digital images has been discussed in the literature for years (Koch et al., 1998; Pollefeys et al., 1999; Hirschmuller, 2008; Pierrot-Deseilligny et al., 2011) Automatic alignment of images and the construction of a full, detailed, precise and realistic 3D model from images is still a difficult task, especially when the images used are not calibrated, and requires large experience and knowledge.

The latest development in using non-metric digital images to construct realistic 3D models of historical buildings are promising. This has been affected by expansion of the possibility of automating image data processing with specialist photogrammetric modelling programs. Utilizing open-source software such as Meshlab, freeware such as 123D Catch and licensed software such as Agisoft PhotoScan Pro, it is now cost-effective to utilize photogrammetry in any project (Preuss, 2014; Diara, 2013). Non-metric images are increasingly often acquired using unmanned aerial vehicles (UAV). For example, they are used in creating virtual and photo-realistic 3D models, both of individual buildings (Pueschel et al., 2008; Uysal et al., 2013; Boroń et al., 2009) and whole cultural landscapes (Brumana et al., 2011). Some research work at archaeological sites has also been designed and performed as well (Sauerbier & Eisenbeiss, 2010; Bykov et al., 2012).

This paper presents the results of experiments in utilising digital images to construct a photorealistic 3D model of a historical building. It discusses the current possibilities of the automated processing of aerial (acquired by UAV) and ground-based images with Pix4Dmapper and Agisoft PhotoScan software.

2. Research experiment description

According to the technical guidelines K-2.7 Principles of taking aerial photographs, the process of preparation and performing a flight for photogrammetry and teledetection should include the following stages:

- selecting the photo-aerial equipment,
- specifying the meteorological conditions of the flight mission,
- preparing a flight design and establishing navigation tolerance,
- designing and signalling of the ground control points,
- the flight,
- examination of the photographic and photogrammetric quality of the images.

The aim of the first stage of the study was to develop the technical task in accordance with the principles mentioned above in order to acquire aerial (UAV) and ground-based digital images of good geometric and radiometric quality. The next stage involved developing the optimum technology for the 3D modelling of a historical building (with the Raphaelsohns' Sawmill in Olsztyn as an example) using only ground-based or aerial non-metric digital images. In the last stage, an experiment was conducted to assess the possibility of 3D modelling with the comprehensive use of non-metric aerial and ground-based non-metric digital images in terms of its labour intensity and precision of elaboration.

The following equipment and software were used in order to assess the possibility of using a block of images acquired with a non-metric camera to generate a 3D model of a historical building:

1. Unmanned aerial vehicle: **DJI Inspire 1** with an FC350 camera.
2. Compact class digital camera: Panasonic **DMC-FT1.**
3. Zoom class digital camera: Panasonic **DMC-FZ30**.
4. Graphic workstation 1: Computer: **HP 640 Workstation** (CPU: Intel Xeon CPU E5-2620 v3; RAM: 48 GB 2,4 GHz; Graphic card: NVIDIA Quadro K2200, 4 GB; HDD: ATA ST1000DM003-1ER1 SCASI Disk Device).
5. Graphic workstation 2: Computer: **HP 640 Workstation** (CPU: 2 x Intel Xeon CPU E5-2620 v3; RAM: 64 GB 2,4 GHz; Graphic card: NVIDIA Quadro K2200, 4 GB; HDD: ATA Hitahi HDS72101 SCASI Disk Device).
6. Software: **Agisoft PhotoScan** Professional Edition, **Pix 4D** Pro mapper.

The cameras used for the experiment are consumer, non-metric cameras and they have not been pre-calibrated. The field tests resulted in 3 blocks of images:

1. 84 images with a Panasonic DMC-FT1 camera – without geo-references.
2. 192 images with a Panasonic DMC-FZ30 camera - without geo-references.
3. 256 images with an FC350 from DJI Inspire 1 - with geo-references.

Each of the blocks was processed four times in order to generate a 3D model of the test building and to compare the use of the selected image acquisition method, the 3D software and the computer unit. A single process of generating a 3D model in Agisoft or Pix4D software consists of 4 steps:

Step 1 – adding a block of images to the project (*align photo*) – images can be added one-by-one or in groups. For non- geo-referenced images it is extremely important to enter them in the right order, because the image processing is done sequentially, with successive stereograms, which are subsequently joined in blocks which, in turn, are further processed. Moreover, this step involves the acquisition of metadata contained in EXIF data of the images being processed, particularly data on the focal length of the camera and the geographical coordinates of the principal point of an image. The data acquired will be used to generate the camera calibration metrics, which will help to obtain the approximate parameters of the external image orientation. Geo-tagged images can be aligned freely, interlinking the images to make a uniform block without localisation in space (generic) and geo-referenced in a selected frame of reference (e.g. PUWG 2000).

Step 2 – building a dense cloud.

Step 3 – building mesh – the software generates a 3D mesh which makes an object surface on a dense cloud. The mesh is generated by the algorithmic creation of a 3D mesh. The applications analysed here can be used for the basic editing of the mesh, e.g. deleting detached elements or closing gaps in the mesh.

Step 4 – building the texture of a building – selecting the mode of applying the texture optimises the method of its storage in the texture atlas, which improves the final quality of the model visualisation.

When evaluating the quality of the generated models, such parameters should be compared as: the number of alignment points, the number of points in the dense cloud and the number of generated polygons. The models created in the experiment were similar in terms of the number of alignment points and the number of polygons; significant differences were observed only for the dense cloud. Table 1 presents a comparison of the parameters for all generated models. The parameters are affected mainly by the selected processing options; modelling was done with default settings in both programs. The tests showed that the performance of the graphic workstation used in the experiment does not affect the model quality.

Table 1. The number of points in a dense cloud of 3D models generated in Agisoft and Pix4D software

Software / Camera	Agisoft	Pix4D
FT1	5 792 999	4 696 298
FZ30	6 213 555	6134 285
Inspire1	8 612 709	10 079 726
FT1+Inspire1	8 951 390	12 505 514

This table clearly shows that the number of generated points does not depend on the software used. Depending on the camera used, the number of generated points was greater in some instances by Agisoft software, while in others by Pix4D. The processing parameters were not changed in either of the programs. Despite the number of points, which reached nearly 30% in some cases, the visual assessment found no significant differences in the quality of the final model. The times needed for the successive stages of transforming a block of images into a 3D model are presented in table 2.

The analysis showed that the difference in the number of steps arises from combining two processes in step 3 in the Pix4D software: generating a mesh of triangles and generating the texture of the object being modelled. In order to be able to compare the labour intensity of different steps in both Agisoft programmes, the processing times for steps 3 and 4 were summed and the result is presented in chart 1.

Table 2. Processing times of successive steps of creation of a 3D model in the tested software (default settings)

No	Image processing stage		Duration	Accrued time	Duration	Accrued time	Duration	Accrued time	Duration	Accrued time
	Agisoft	Pix4D	Agisoft Graphic workstation 1		Pix4D Graphic workstation 1		Agisoft Graphic workstation 2		Pix4D Graphic workstation 2	
		Panasonic DMC-FT1								
1	Align Photos	Local Processing	0h 14m		0h 11m		0h 6m		0h 8m	
2	Build Dense Cloud	Point Cloud Densification	0h 8m	0h 22m	0h 5m	0h 16m	0h 6m	0h 12m	0h 6m	0h 14m
3	Build Mesh	Generate 3D Textured Mesh	0h 6m	0h 28m	0h 1m	**0h 17m**	0h 6m	0h 18m	0h 2m	**0h 16m**
4	Build Texture		0h 1m	**0h 29m**			0h 1m	**0h 19m**		
		Panasonic DMC-FZ30								
1	Align Photos	Local Processing	1h 3m		0h 29m		0h 23m		0h 23m	
2	Build Dense Cloud	Point Cloud Densification	0h 5m	1h 8m	0h 21m	0h 50m	0h 4m	0h 27m	0h 10m	0h 33m
3	Build Mesh	Generate 3D Textured Mesh	0h 5m	1h 13m	0h 3m	**0h 53m**	0h 5m	0h 32m	0h 3m	**0h 36m**
4	Build Texture		0h 2m	**1h 15m**			0h 1m	**0h 33m**		
		DJI Inspire1								
1	Align Photos	Local Processing	1h 59m		0h 45m		0h 43m		0h 33m	
2	Build Dense Cloud	Point Cloud Densification	1h 0m	2h 59m	1h 3m	1h 48m	0h 33m	1h 16m	0h 26m	0h 59m
3	Build Mesh	Generate 3D Textured Mesh	0h 6m	3h 5m	0h 5m	**1h 53m**	0h 6m	1h 22m	0h 6m	**1h 5m**
4	Build Texture		0h 2m	**3h 7m**			0h 3m	**1h 25m**		
		Panasonic DMC-FT1 + DJI Inspire1								
1	Align Photos	Local Processing	3h 27m		1h 4m		1h 16m		0h 48m	
2	Build Dense Cloud	Point Cloud Densification	1h 0m	4h 27m	1h 41m	2h 45m	0h 35m	1h 51m	0h 37m	1h 25m
3	Build Mesh	Generate 3D Textured Mesh	0h 6m	4h 33m	0h 4m	**2h 49m**	0h 7m	1h 58m	0h 6m	**1h 31m**
4	Build Texture		0h 3m	**4h 36m**			0h 2m	**2h 0m**		

An analysis of the test results indicates that the automated processes are more effectively and quickly carried out by the Pix4D software. For example, a comparison of the time needed by both applications during the first step of processing a block of images acquired by an unmanned aerial vehicle marked on the diagram as [I1], Align Photos shows that Agisoft needed 119 minutes to complete the process on graphic workstation no. 1 and 43 minutes on graphic workstation no. 2, whereas Pix4D carried out this step in 45 and 33 minutes, respectively.

Examples of images taken for this experiment and the images rendered during the process of generating a 3D model with the Agisoft and Pix4D software are presented below (Fig. 1-3).

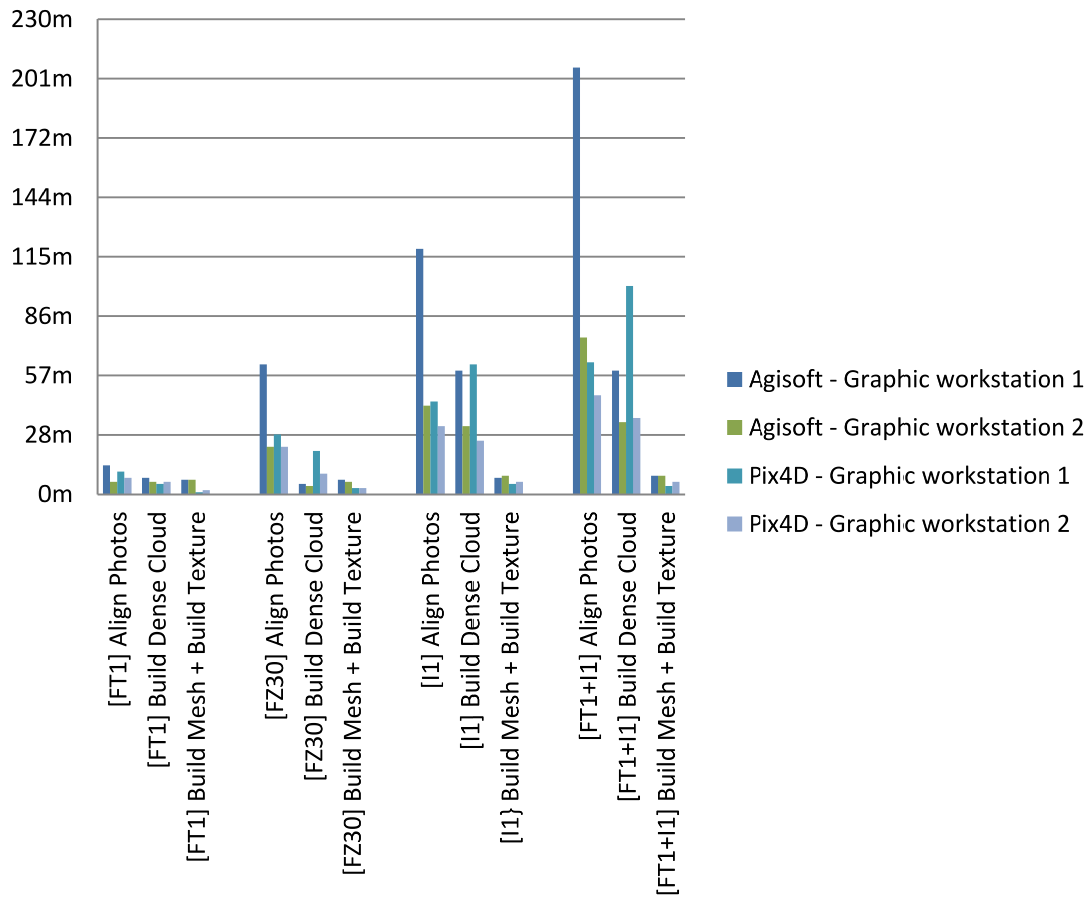

Chart 1. Times of processing of different blocks of images, broken down into stages, software and graphic workstations

Fig. 1. A geo-referenced image taken with a non-metric digital camera FC350 from a quadrocopter - DJI Ispire 1 (resolution 12 Mpix)

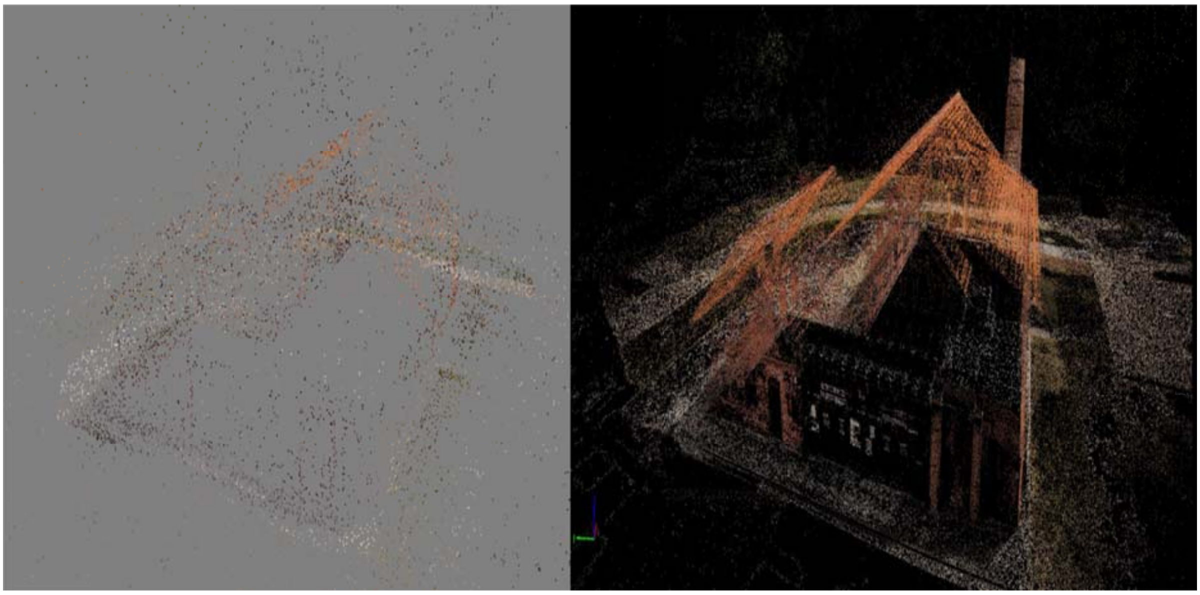

Fig. 2. Image (Points Cloud) generated by the tested software:
on the left – Agisoft Photo Scan Professional Edition, on the right – Pix4D Pro mapper

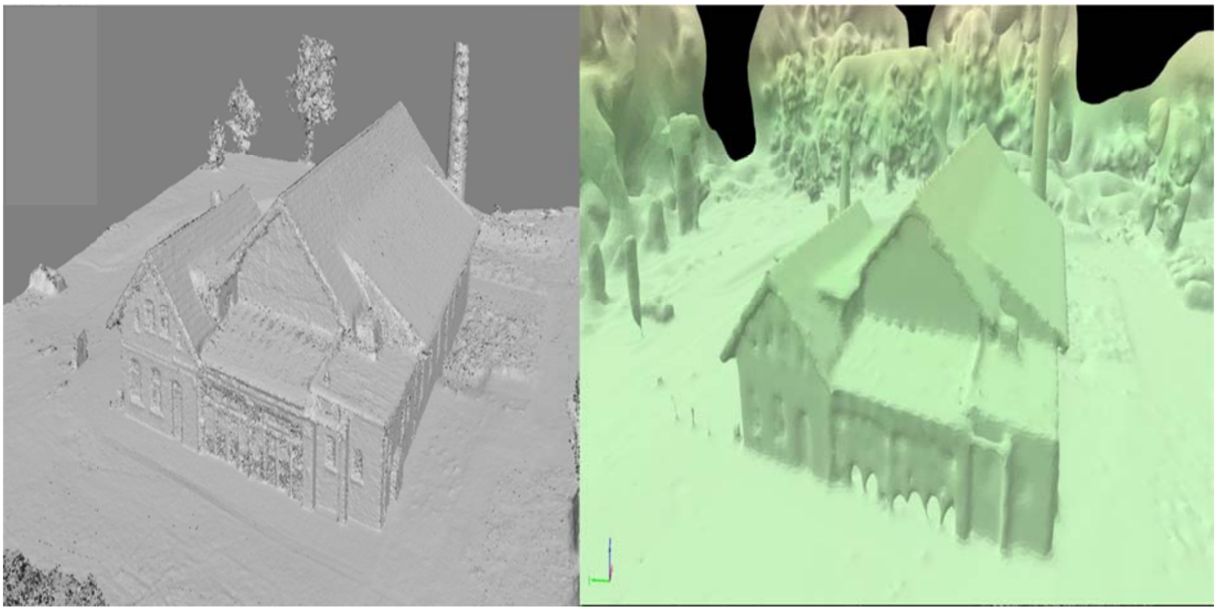

Fig. 3. Image (Dense Cloud) generated by the tested software:
on the left – Agisoft Photo Scan Professional Edition, on the right – Pix4D Pro mapper

Fig. 4. Image (Texture) generated by the tested software:
(on the left – Agisoft Photo Scan Professional Edition, on the right – Pix4D Pro mapper

3. Conclusions

The following conclusions can be drawn from this experiment:

1. In order to increase the precision of the generated model, the following points are needed:
   1.1. To develop a plan of flight which takes into account the features of the building whose model is generated;
   1.2. The flight must be done in the right lighting and weather conditions:
      - the sun at the zenith (this minimises the length of the shadow and the size of the shaded area of the building);
      - slightly cloudy weather (reduces the tonal range of the images, prevents formations of sharp transitions between brightly lit and shaded areas);
      - no precipitation (in principle, unmanned aerial vehicles are not suited to flying when it is raining; rain drops can contaminate the camera objective, making patches visible in images);
      - no wind (strong wind or gusts hinder precision flight, both in manual control mode and in an autonomous flight);
   1.3. Properly select the model of the unmanned aerial vehicle and the type of camera;
   1.4. Calibrate the camera;
   1.5. Use signalled photopoints;
   1.6. Select processing parameters properly;
   1.7. Generate a model in a supervised process.

2. The camera should have:
   - calibration data;
   - an RGB sensor with a wide angle and small barrel distortion;
   - a resolution of at least 12 Mpix;
   - manual settings;

- controllability within the range from 90 to 180 degrees (from the objective directed forwards to the objective directed vertically downwards).

3. To increase the geometric and radiometric quality of the 3D model:
   - generating a full 3D model of the building structure is not possible only from blocks of ground-based photographs;
   - increasing the number of photographs does not directly improve the quality of the model, but it increases the amount of time needed to process it;
   - the model quality is directly affected by selected processing parameters;
   - the quality of a 3D model generated automatically, in a non-supervised process, is sufficient for model applications, e.g. for creating 3D animations or for making spatial analyses (e.g. insolation analyses);
   - the quality of the models generated in both programmes is similar and the differences stem from slight differences in default settings.

The experiments and analyses have shown that when certain parameters established in an experiment are followed, such as the type of an unmanned aerial vehicle and the navigation software, digital camera and methods of its calibration, the principles of designing and performing the flight and properly selecting the data processing software, the process of developing the stock-taking documentation for a historical building moves from the standards of analogue to digital technology with considerably reduced cost. This process can also be used to develop technical guidelines to prepare stock-taking documentation for a historical building.

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