Generating of Building Facades Orthophotoplans with UAV and Terrestrial Photos

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Abstract. The study aims to show the possibility of using terrestrial laser scanning and unmanned aircraft as a tool for obtaining high resolution photogrammetric material in order to develop colourful, metric orthoplans and 3D models of an architectural object. The object of the study was the church dedicated to Saint. Bartholomew the Apostle in Mogila and the chapel of St. Malgorzata at Salwator in Krakow. Field activities of the church of St. Bartholomew the Apostle in Mogila covered the execution of the raid by means of the unmanned aerial vehicle DJI Phantom 4 Pro, acquisition of ground-based photos with a non-metric Nikon D3100 camera, and the measurement of photopoints with an electronic total station. UAV was manually moved to a height of 20m in relation to the roof of the church, just above the turret (the turret located above the intersection of the transept with the nave). Then, the radius was specified by moving 10m away from the edge of the subject. After setting the minimum orbital speed (to avoid blurring the images), the object was automatically looped. In this mode, 76 images were recorded around the whole object. In the next stage the flight took place by hand. At a height of 10 m from the ground, 32 photos of the southern and eastern walls and a part of the western wall were made from a distance of approx. 15 m from the façade. After completing the BSP raid, the SLR was started. Obtained in this way, 120 photos with a longitudinal base of approx. 3.30 m (coverage above 70%). The camera allowed to reach places inaccessible to the UAV and take photos of the lowest parts of the facade, maintaining an angle close to the straight one in relation to the vertical plane. The last of the planned field activities was the measurement of the photopoints on the geodetic network for the purpose of later giving the object georeference and the right scale, as well as optimizing the position of the camera and orientation of the photos. The last, final stage of the work was the creation of orthophotoplans for four elevations. The summary discusses the results of the work and assessed the capabilities of unmanned ships as part of the creation of orthophotoplans and the creation of 3D models. The measurement of the object was made of 7 sites providing a common area coverage. In addition, 8 points were distributed evenly around the measured chapel indicative in the form of matte, glass balls placed on the ground, necessary in the process of clouding points from individual positions. The number of posts and balls was dictated by the nature of the measured object and the need to obtain as few dead zones as possible. Despite the efforts, it was impossible to avoid the appearance of dead zones, which are located in the place of setting up the lighthouse on the dome of the chapel. An additional
obstacle turned out to be the trees growing in the vicinity of the chapel, which partially covered with its walls the walls of the building. The effect of field work was to obtain 7 images of point clouds and 8 images of landmarks. After cleaning individual images, the cloud was created and the 3D image of the object was obtained and an average error of 3 mm was obtained. The final effect of cleaning and depositing a point cloud was the three-dimensional shape of the object, which served the last stage of the work, which was modeling. Due to the conditions in the area, the cloud received had some dead zones, including the one at the connection of the lighthouse with the dome. After completing the orientation of the point cloud, the final stage of this study was to create a 3D model of the chapel.

1. Introduction

Scanning technology is currently one of the fastest growing technologies on the market. Many years have passed since the introduction of the first laser scanner and this technology has found its application in various industries. The interest in this subject is still growing. Technological development means that 3D scanners are systematically improved, which directly affects the extension of areas in which they can be used: from surveying and industrial surveys, through medicine, forestry, forensics and many others [1]. Laser scanning allows easy and quick acquisition of three-dimensional data about objects with a complex structure and construction. It happens that this technology allows you to measure in a place where traditional methods would not be possible to use. Laser scanning has revolutionized measurement methods in many areas - one of them is the inventory measurement of historic objects. Research on the use of ground-based scanning for the registration of cultural heritage objects has been conducted for several years around the world [2], [3], [4], [5], [6], [1], [7], [8], [9],[10]. This is evidenced by the growing number of publications on the use of this technology for documentary purposes. The use of this method enables the measurement of complex objects, structures and architectural details with the results obtained in virtually real time, while retaining the millimeter accuracy. The point cloud, the result of this measurement, is an excellent base for creating 2D and 3D documentation [11],[1], [12]. Unmanned Aerial Vehicle (UAV) has become very popular in recent years. Many authors have successfully used UAVs in different contexts and with different purposes for large-scale documentation of Cultural Heritage. Moreover, these platforms represent a low-cost alternative to the classical aerial photogrammetry technique [11], [13], [14]. In the last few years, UAV platforms have become one of the most employed systems for mapping and 3D modelling issues. The main advantages that these platforms have contributed to the field of archaeological documentation concern the low-cost alternatives to the classical manned aerial photogrammetry technique [15], [16]. Until now, they have been associated with military activities, and now they are increasingly used for both entertainment and commercial purposes in the service sector [17]. In the past the development of UAVs was primarily driven by military purpose, e.g. surveying of hostile territories. During the last few years the use of UAVs combined with cameras for civil applications (e.g., in geomatics) has largely increased [16], [18]. As proposed by [19], we refer to the combination of UAVs and digital cameras as UAV-photogrammetry. [19] defines UAV-photogrammetry as a platform for photogrammetric acquisitions, which can be carried out remotely controlled, in semi-autonomous or autonomous mode [20]. Their advantages were noticed not only by photographers, but also by surveyors or designers. In the future, laser scanning with the use of UAV will surely be popularized, which will further expand the field for UAV applications. However, UAV technology now offers results that are inaccessible to manned vessels, taking into account at least the size of the field pixel, low cost and short time of the raid. UAVs are therefore great, as an intermediate tool between terrestrial measurements and traditional large-scale aerial imaging.

2. Research work

The historic parish church dedicated to Saint. Bartłomiej Apostol is located in the Nowa Huta district in Krakow (Figure 1). The temple is under the supervision of clerical brothers from the Cistercian Abbey. The church is one of the objects of the Krakowska Open Wooden Architecture Route. It is a
building made of larch wood in the Gothic style, with a unique in Poland three-nave structure, covered with shingle. The chapel of St. Margaret and Judith (Figure 2), is located on a small hill between the Norbertine monastery and the church of the Holy Salvator in Salwator district in Krakow. The chapel is built in a carcass construction on an octagonal plan, covered with a flat dome covered with shingle and topped with a lantern.

Figure 1. View from the south-west of the church dedicated to St. Bartholomew the Apostle [21]

Figure 2. The chapel of St. Margaret and Judith [22]

The measurement of the church in Mogila, including the UAV flight, was carried out with the help of the Phantom 4 Pro unmanned aerial vehicle with the integrated camera FC6310. The GNSS Topcon HiPer II receiver with the Tesla controller was used to create the measuring network, accuracy of which in horizontal positioning RTK technology is 10mm + 1ppm in and in vertical is equal 15mm + 1ppm. The measurement of the photopoints was made with the use of Topcon GPT-7503 electronic tachymeter, which is characterized by the accuracy of angle measurement at the level of 3 " and the distance ± (2mm + 2ppm). A Nikon D3100 digital SLR camera with a Nikon DX AF-S Nikkor 18-55 SWM VR Aspherical 0.28 m lens was used to make the ground photos. Creation of orthophotoplanes
took place in the Agisoft PhotoScan Professional software. The first stage of the work was to carry out an unmanned aerial vehicle (UAV) flight. After the start, it turned out that it is not possible to save the calculated distance of elevation photographing from the eastern, northern and western due to the small space separating the building from nearby tall trees. It was necessary to take pictures at a definitely higher level. As a result, the flight was carried out in two approaches. In the first stage, the Point of interest (POI) mode was used (Figure 3), in which the UAV moves on a circle with a given radius over a given point, maintaining a certain height and speed, keeping the camera pointing at the starting point. The unmanned aerial vehicle was manually raised to a height of 20 m in relation to the roof slope of the church, exactly above the turret (the turret located above the intersection of the transept with the main nave). Then the radius was determined by directing the UAV to a distance of 10m from the edge of the photographed object. After setting the minimum orbital speed (to avoid blurring the images), the automatic circulation of the object started. The shutter was released every 2s to maintain longitudinal coverage above 70%. In this mode, 76 images were recorded around the entire object. And at the height of 10 m from the ground, 32 photos of the southern and eastern walls and parts of the western wall were made.

![Figure 3. Sample photo taken during the flight in the Point of interest mode [21](image)](image)

After the UAV flight, a further measurement was started. Using a Nikon D3100 non-metric camera, 120 photos were taken with a 3.30 m long base (coverage above 70%). Photographs were taken in places unavailable for UAV and for the lowest parts of the façade, with the angle close to the straight in relation to the vertical plane. In total, 228 photos of the temple were obtained, where the first series starting from the ground level are photographs from the non-metric camera, in the next row there are photos from manual flight, and the last row contains photos from automatic flight in POI mode. The last of the planned field activities was the measurement of the photopoints basing on the geodetic network for the purpose of later giving the object georeference and proper scale, as well as optimizing the position of the camera and the orientation of the photos. The network was established in the form of four points, stabilized with wooden stakes located one on each corner of the church, so as to cover all of the walls with measurements. All 20 photopoints were measured using the polarization method in the mirror-free mode. Subsequently, masking of selected photos was started (Figure 4), which contained unwanted elements of the background, which could have a negative impact on the result of matching and further building the point cloud (troublesome areas such as vegetation covering the frame).
Figure 4. The effect of the process of masking photos [21]

With the help of the converter built into the PhotoScan software, the position coordinates have been transformed into the 2000 system in which the coordinates of the photogrammetric network were also determined. At this stage, it was possible to proceed with the adjustment of the photos. As a result, the position and orientation of all cameras and the initial, thin point cloud were obtained, as well as tie points in the number of 114043 points (Figure 5).

Figure 5. Initial point cloud and determined camera positions after adjustment [21]

Key points found by the algorithm can be displayed in photographs by selecting one of the options of the Agisoft PhotoScan Professional program (Figure 6).
In the next phase of the work, a photogrammetric network was introduced into the project in the form of XYZ coordinates of photopoints in a text file (Figure 7). Each point was indicated on at least two photos by means of a marker. As a result, the position error of the photogrammetric network was 0.01m.

The next step was to generate a dense cloud of points based on the calculated cameras positions. Regarding the fact, that the cloud was to be used to create a grid of triangles with advanced geometry (for supporting orthophotoplans on it), high quality of points generation and a moderate depth filtering algorithm were selected, in order to not lose valuable details of the object. After the process, 29,212,816 points were created. The cloud required purification from noise, as well as elements that were not subject to elaboration such as the surroundings and vegetation. As a result of cleaning, the cloud has been reduced to 10,333,96 points (Figure 8). On its basis, a mesh of triangles was prepared, selecting high density settings, with interpolation of losses set on. The grid in the form of a wireframe view is shown in Figure 9.
The last stage of works in the Agisoft PhotoScan program was the creation of orthophotoplans for four elevations. Orthophotoplans were generated by selecting the surface mapping, as a mapping type, and as the mapping surface - the planes created by the axes of the geodetic system (southern wall - Front XZ plane, west wall - Left YZ, north wall - Back XZ, eastern wall - Right YZ). As a result, 4 orthophotoplans with a pixel of 3.0 mm were formed. This is a worse value than expected to achieve, because the impact on the deterioration of the result had a level for taking pictures by UAV. Considering the location of the research object and its availability for UAV technology, it was necessary to take into account the risk, of not keeping the size of a 2mm field pixel previously assumed. Based on the visual assessment, it was found that the best quality is of the orthophotoplan of the southern wall (Figure 10). It does not have any visible geometric or colour distortion, it also has a good sharpness and the level of detail. This is due to the fact that the southern façade was very well illuminated and was photographed using UAV from the lowest level. Orthophotoplans eastern (Figure 11) and western (Figure 12) are characterized by only minor defects. The northern orthophotoplan is the worst (Figure 13). Due to many trees photographed on the pictures and the lack of visibility of the wall from the UAV level, this orthophotoplan has numerous, visible errors in mosaic on the level of the roof and turret, as well as discoloration despite active colour correction. Despite attempts to deactivate individual images of lower quality from the mosaic process, the state of generated northern orthophotoplan could not be improved. At this point, attention should be paid to the problem of vegetation for the photogrammetric method of orthoimagining. Situations in which any unnecessary objects may be in the frame, covering the photographed object should be avoided. Similarly, on western orthophotoplan on a fragment of the roof, branches of trees and discoloration in their vicinity are visible near the edge adjacent to the north elevation. On the eastern orthophotoplan, however, there are small, distorted areas of low sharpness on the shingle surface, in this case, most likely caused by shading this side of the building during shooting. However, Nikon's non-metering camera has managed this effect, as the shortcomings of this type do not occur on the walls, up to the roof height.
The second object of research was the chapel of St. Malgorzata and Judith. The chapel was measured using a terrestrial laser scanner Leica Scan Station P40. The measurement was made from 7 positions providing a common coverage area. In addition, 8 orientation points are evenly distributed around the measured chapel in the form of matte glass spheres placed on the ground, necessary for the joining of clouds of points from individual positions. The number of posts and spheres was dictated by the nature of the object being measured and the need to obtain as few dead zones as possible. Despite the efforts, it was impossible to avoid the appearance of dead zones, which are located in the place of setting up the lantern on the chapel dome. An additional obstacle turned out to be the trees growing in the vicinity of the chapel, which partially covered one of the walls of the object with branches. The effect of field work was the obtaining of 7 images of point clouds and 8 images of orientation points. The point cloud processing was performed in Leica Cyclone 3D program, cleaning it from unnecessary elements located outside the object being measured. After cleaning individual images, a cloud was assembled. The 3D image of the object was obtained with an average error of 3 mm. The result of cleaning and assembling of the point cloud was the three-dimensional shape of the object that
served the last stage of the work which was its modeling. Due to the terrain conditions, the received cloud had some dead zones, including the one at the connection of the lantern with the dome (Figure 14).

Figure 14. The point cloud of the object being measured [22]

After completing the orientation of the point cloud, the final stage of this study was to create a 3D model of the chapel.

Three-dimensional object modeling can be done in several ways:

- frame method - consisting in defining the position of vertices and edges present in the object;
- solid method – unambiguously represents the object, defining its borders, surfaces and topological orientation; emphasizes physical fidelity;
- catalog method – based on the catalogs of objects that are automatically assigned by the program to individual objects in the point cloud. Very often used in the documentation of industrial installations;
- meshing method – 3D model consists of triangular planes (polygons) generated on the basis of the point cloud.

The study uses the first of these methods, i.e. a framework method. During the modeling most of the outer edges and door and window openings were captured. As a result, a simplified model was obtained that reflected the actual image of the object being measured (Figure 15).

Figure 15. Framework model of the object – isometric projection [22]
3. Conclusions
This paper describes the course of operations related to the generation of orthophotoplans of the facades of the building with the help of UAV and terrestrial images, and the use of terrestrial laser scanner for 3D modeling of an architectural object. Problems connected with obtaining data resulting from the limitations of UAV technology and inconvenient location of the test object are also presented. The generation of orthophotoplans on the basis of photography is a method that is particularly dependent on the quality of the photos. The model and parameters of the camera are very important here. In this case the reflex camera was definitely better, but it was not able to photograph the whole object due to its height. Therefore, it was necessary to use UAV. In the case of an unmanned aircraft the difficulties caused by trees around the object should be taken into account. They prevented a low-level flight around the entire building and obscured part of the façade, causing the lack of mutual overlap in the pictures of the same part of the wall relative to terrestrial images. The least problems with coating and elaboration were caused by a fragment of the building from the south, the most exposed and well-lit during shooting. Ground-level photographs along with photographs from the UAV were in this case a mutual complement, giving a very good final result. If similar conditions prevailed for the entire object, defects on orthophotoplans would certainly be avoided, such as errors in mosaic of the north elevation. Due to field difficulties and the occurrence of dead zones in the scanning environment and reduced density of point clouds as a result of compression, creating the model was difficult and it was impossible to capture all the edges of the building's body. However, this does not change the fact that the model faithfully reproduces the appearance of the object and can be re-used. This is a good example of the fact that laser scanning is suitable for documentation of architectural monuments.

The progressive development of technology and informatics begins to affect most areas of life. These changes largely affect broadly understood engineering. The use of laser scanners in the documentation of architectural objects is a perfect example. In addition to the measurable benefit in the form of digital building documentation along with all its technical parameters, we get a product that can be used in tourist promotion. It is a form that reaches the recipient in a much better way, because, unlike words, it more affects the imagination and stimulates curiosity. Which is quite significant and extremely important in the case of monuments.

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