Development of Photogrammetric Documentation of the Borough at Biskupin Based on Archival Photographs - First Results

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Abstract. This paper presents the initial results of research work carried out as part of a project entitled "*The design of development of the Lusatian culture settlement at Site 4 at Biskupin: pre-war research work*" financed by the Ministry of Culture and National Heritage, within the National Heritage 2016 Programme, "Conservation of archaeological monuments". The high quality of photographic documents results from the professional, technical and organizational facilities organized by the Biskupin Expedition during the period 1934-1939. A group of photographs acquired from various heights at that time were selected (an aeroplane, a barrage balloon, an observational balloon and terrestrial photographs); these were used for further processing. Using photographs, a true orthoimage, 3D vector models and a 3D visualization of photorealistic models were generated. This paper presents the methodology and stages of the technological process of generation of photogrammetric documentation based on archival data. The benefits and disadvantages of the conventional photogrammetric approach are discussed, and a modified approach involving the application of commonly-used computer vision algorithms is also presented.

Keywords: Archival photographs · Borough at Biskupin · 3D modelling · True-orthimages · Vector products · Automatic image processing

1 Introduction

Cultural heritage is evidence of the past, and historical objects are a very important part of this cultural legacy. A high level of participation from disciplines involved in spatial documentation is required within the field of heritage conservation. The approach used by numerous specialists towards conservation through documentation, initially understood as technical records of historical artefacts which it was impossible to maintain in physical form, has recently been considerably widened. Documentation has become an important tool for preventive conservation, as well as the basis for the media and social transfer of a historical object in the virtual space [1]. In general, geometric documentation is an inseparable part of the documentation of a historical object [2].

Photogrammetric documentation may form the basis for the reconstruction of a historical object, or, if the original documentation does not exist, may be used as a comparative material for reconstruction of a similar object. Cultural heritage objects have traditionally been archived in various forms, such as drawings or sketches; when technology developed, these were measured and documented with the use of analogue metric cameras (mono- or stereometric), and graphical or analytical documentation was generated. Using archival photographs and vector documents, as well as modern data processing techniques, models of non-existent cultural heritage objects may be generated and visualized.

2 Methodology

The conventional photogrammetric approach consists of the use of analogue photographs which create so-called-stereograms, used for stereodigitization and generation of vector maps. This approach is required to meet a series of geometric conditions (such as coverage and base/distance ratio) in order to achieve the required accuracy and the possibility of realizing a stereoscopic effect. Modern photogrammetric data processing is fully automated, using a combination of photogrammetric algorithms and computer vision (CV); this allows self-calibration, orientation of photographs and 3D reconstruction [3]. This method is based on searching for the same primitives within at least two photographs or groups of photographs of any geometry. A primary feature of the image-based method is the possibility of image correlation during the 3D reconstruction. This problem has been studied for more than 30 years; however, many problems still exist, such as the lack of full automation, occlusions, poor or non-textured areas and repetitive structures [4]. The CV algorithms are designed to give digital photographs of high radiometric quality and sufficient image resolution. The processing stage of digital photographs aimed at the development of 3D models consists of three basic steps. The first of these utilizes an automatic approach known as structure from motion (SfM), which allows the determination of interior and exterior orientation elements and, indirectly, the "scarce cloud of points". The second utilizes algorithms applied in multi-view stereo to automatically densify these clouds of points. The final step is the reconstruction of the surface and texturing [5, 6]. This approach is widely applied in digital photography; however, in analogue photography it generates many difficulties and therefore is not a fully automated process. This paper discusses issues concerning the processing of archival photographs with the use of modern image-processing tools.

3 Performed Experiments

This paper presents the initial results of research work carried out within a project entitled, "The design of development of the Lusatian culture settlement at Site 4 at Biskupin: pre-war research works" financed by the Ministry of Culture and National Heritage, within the National Heritage 2016 Programme "Conservation of archaeological monuments" (www.biskupin.pl).

3.1   Source Data Characteristics

The high quality of pre-war photographic documents is a result of the professional technical and organizational facilities organized by the Biskupin Expedition during the period 1934-1939, as well as from the involvement of Polish military assets for this purpose. As part of this project, 800 photographic glass plates were inventoried with the use of a photogrammetric scanner of resolution 3200 dpi. A group of photographs acquired from various heights were selected (an aeroplane, a barrage balloon, an observational balloon and terrestrial photographs). In addition, vector data processed during archaeological works (scale 1:10) were also utilized.

3.2   Completed Research Work

The effective use of archival data requires appropriate preparation and processing of photographs (Fig. 1).
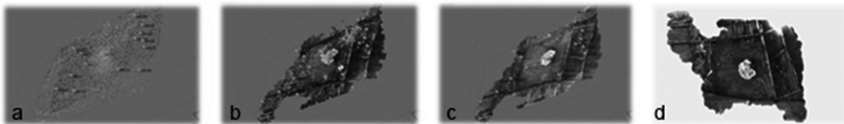

Fig. 1. Diagram of processing archival photographs (a) mutual orientation and manual measurements of tie points on photographs; (b) the dense cloud of points; (c) the textured digital surface model (mesh); (d) true ortho-image

Division and selection of photographs. Available archival data included multi-temporal photographs acquired from various heights. This required an initial division of photographs with regard to their locations and acquisition heights. For this purpose, a "top-down" approach was assumed (Fig. 2).
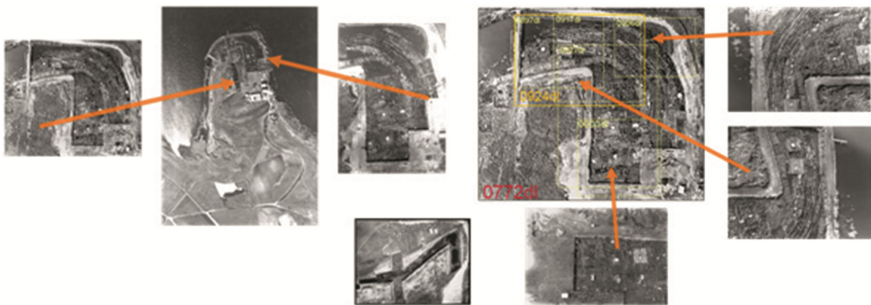

Fig. 2. Approximate locations of photographs: the "top-down" approach

The aerial photograph which covered the entire Biskupin Peninsula was taken as a reference image. Following this, photographs of particular parts of the settlement were searched for. This task was not straightforward, due to repeating elements in the

construction of the settlement; this therefore required a deep analysis of the construction to be performed in cooperation with employees of the State Museum at Biskupin. Photographs were also divided according to the heights of acquisition; this simplifies the automatic processing of photographs by means of the "Chunck" functions in AgiSoft software.

Orientation of photographs (SfM). Ordered groups of points were used to orientate the photographs; these were processed using AgiSoft tools. During the first approach, automatic searching for tie points was applied without manual measurements. As a result, incorrectly orientated photographs were obtained. A scarce cloud of points almost correctly generated should create a plane; in this case, a parabolic surface was created. In order to achieve the correct orientation of photographs it was necessary to perform manual measurements of tie points, distributed according to the conventional von Gruber approach (Krauss, xxx). Selected tie points were distributed on various planes in order to ensure variations in depth. In the conventional approach, at least six tie points are required; however, the authors decided to increase the number of tie points to ten. This allowed improvements to the orientation of oblique photographs as compared with nadir photographs.

In order to geo-reference photographs in relation to archaeological stations, photogrammetric control was developed based on vector drawings at a scale of 1:10. The mean accuracy of the exterior orientation of photographs in the reference system was approximately 1 cm.

Generating a dense cloud of points (multi-view stereo) and the digital surface model. Following the orientation of photographs, the next step was the densification of the cloud of points, carried out with the use of algorithms applied in the multi-view stereo approach. When archival photographs are processed, several difficulties related to generation of the depth map may appear unless initial radiometric processing is performed. Archaeological excavations had been carried out over various periods within the investigated areas; it was therefore decided to generate spread point clouds for each excavation. The digital surface model in the TIN structure was generated based on the generated cloud of points. When the resulting clouds of points and the digital surface model were analysed, some incorrectness in the obtained dataset was noticed; the obtained cloud of points was characterized by a grainy surface structure. This resulted from searching for characteristic points in the penultimate level of the pyramid of images and the variations in quality and conditions of the processed photographs. An additional factor influencing the quality of the resulting digital surface model is the low value of depth of the processed elements. The lack of data is visible in the cloud of points, resulting from difficulties related to the restoration of the repeating structure of the elements of construction, which is difficult to process using MVS algorithms. In future experiments it will therefore be necessary to restore the missing elements of the terrain surface, based on manual measurements of the corresponding features of images using other software tools.

Orthorectification and mosaicking of photographs. The final stage of true-ortho generation was classification and mosaicking of photographs (Fig. 3). For this purpose,

photographs acquired from the lowest possible height were selected, in order to ensure the smallest possible GSD value. In addition, photographs with slight blurring, which were used in the orientation process of the photographs, were eliminated at this final stage. For the southern and eastern fragments, a GSD value of close to 50 cm was calculated (Fig. 3A). This resulted from the scale of the photographs, which were mostly acquired from an aeroplane and the barrage balloon. The northern and eastern parts were projected using balloon photographs from a lower height, corresponding to a GSD value of approximately 10 cm (Fig. 3B).
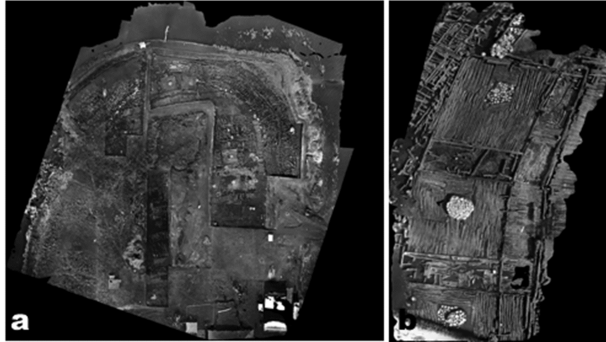

Fig. 3. Examples of true-ortho (a) GSD 50 cm; (b) GSD 10 cm

Visualization and 3D modelling. When archival photographs are used in archaeological work, two approaches to 3D modelling may be applied. Due to the specific features of this work and the assumptions of the project, two types of models were proposed. A non-metric model was created, based on individual photographs and using Blender software (Fig. 4).
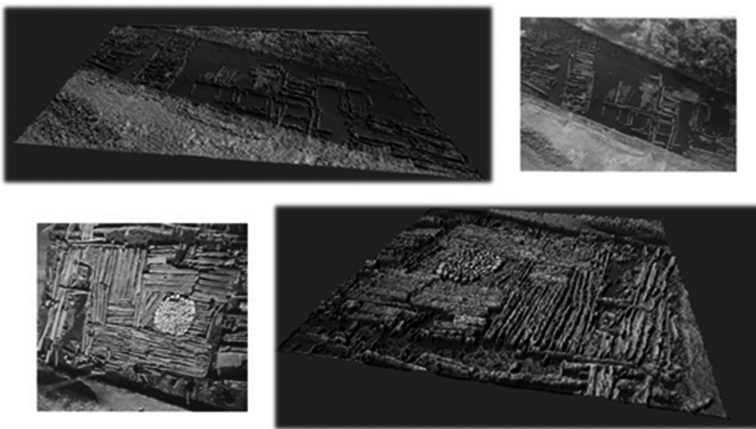

Fig. 4. Examples of visualization of models generated from individual photographs using Blender software

This model is used for the photointerpretation of the structure and the relationships between the elements of the settlement construction. It allows for the separation of the constructional layers created in different periods of the settlement's history. According to the opinions of archaeologists, many constructions exist in the analysed areas, and were created at different times. The final visualization allows for the confirmation or contradiction of the formulated hypothesis. The second approach in the 3D modelling of constructions allows for the geometric dimensioning of constructional elements. At this stage, Trimble Sketch Up software was used. Figure 5 presents the models, including the 3D model matched in the photographs, and a photorealistic 3D model of the fireplace and a fragment of the floor.
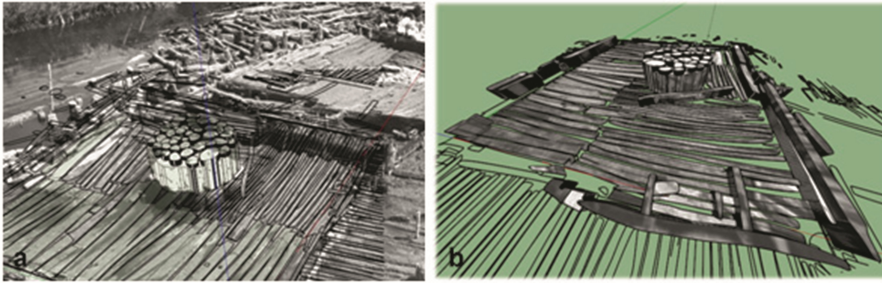

Fig. 5. A 3D model (a) matched in the photograph; (b) a photorealistic model of a fireplace and a floor fragment

4   Conclusions

Widely-used computer vision algorithms were used for data processing. In the authors' opinion, the use of those algorithms to process scanned photographs did not lead to successful results in several cases. The experiments carried out showed unreliability when full automation was used; it was therefore necessary to support the algorithms with manual measurements of tie points. All photogrammetric products will be entered into the planned HGIS database, and the designed and developed modules of the HGIS database will allow the display of objects processed at the stage of virtual reconstruction of relics of the settlement's development.

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