Analysis of low-cost photogrammetric procedures in the process of historical objects survey

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Abstract

The documentation of cultural heritage is an essential part of appropriate care of historical monuments, representing a part of our history. It represents the current issue,for which considerable funds are being spent, also for the survey of immovable historical monuments in form of castle ruins, among the others. Non-contact surveying technologies–terrestrial laser scanning and digital photogrammetry are among the most commonly used technologies, by which a suitable outputs can be obtained, however their use may involve an excessive increase in financial expenses. In recent years, various types of software products and web services based on the SfM (or MVS) method and developed as an open-source software, relying on the basic principles of photogrammetry and computer vision, have started to get into the spotlight. By using these software, acquired digital images of the given object can be processed into a point cloud, serving directly as a final output or as a basis for further processing. The aim of this paper, based on images of various historical objects obtained by the DSLR Pentax K5, is to assess the suitability of different types of open-source software and their reliability in terms of surface reconstruction and photo-texture quality for the purposes of historical objects survey.

Key words: low-cost photogrammetry, structure from motion, historical objects

INTRODUCTION

Every country in the world has its history and culture, almost everywhere we can find historical monuments in the form of different historical buildings, castles, chateaus, archaeological sites, areas, findings and other movable and immovable monuments. These objects are part of the cultural heritage of each country, it is necessary to protect them in a certain way, take care and preserve them for future generations. And just for these purposes, it is necessary to document our cultural heritage in an appropriate way. In today's world full of technology, there are several possibilities to obtain these results. At present, mainly two technologies can be considered as the most advanced and suitable for historical objects survey – laser scanning and digital photogrammetry.

Each of these technologies has its advantages and disadvantages (regarding the resulting accuracy for various distances of scanning vs. imaging, mobility, radiometric and geometric resolution, or purchase cost)[1]. At present, a number of requirements - mainly high accuracy, level of detail, complexity and reliability of data that in turn must have a geometric and visual quality with effective collection and low volume of data, are imposed on the resulting data obtained by any of these technologies. Just achieving a low purchase cost while acquiring reliable results, which will meet the above requirements, is one of the major trends in the 3D surface reconstruction, computer modelling and documentation of cultural heritage [2]. The latest technologies and methods of laser scanning and digital photogrammetry meet these requirements in a large extent, but the purchase cost of hardware and software may be still too high in some cases.

Therefore, a lot of effort has been made for the development of new methods for computer modelling from photographic images, reconstruction and display of 3D models. Based on this, various algorithms and software dealing with surface and object reconstruction from images began to emerge.

OPEN-SOURCE PHOTOGRAMMETRIC SOFTWARE

The *SfM* method (*Structure from Motion*), which involves the simultaneous determination of interior and exterior orientation parameters and reconstruction of 3D structure captured on images, or *MVS* (*Multi-View Stereo*) representing an algorithm for image matching between a set of multiple image stereo pairs, are two main principles upon which those software operates. In the past, algorithms for surface reconstruction based on these principles were useful mainly for visualisation purposes and not for photogrammetry and mapping. But nowadays, thanks to technological advances, a large number of images may be automatically oriented within an arbitrary defined coordinate system using various algorithms.

Currently, there are already several various software using the above principles, with some of them being available for several years (a detailed procedure for solving the problem of fully automated, accurate and reliable matching between a set of multiple images was introduced as early as 1988 [3]) and they are progressively being improved and also give rise to other new tools and software. Among the best known, we can include the *SIFT*algorithm [4], for obtaining distinctive invariant features from images, which can be further used for reliable matching between these images, the system for generating 3D digital models from images[5], the software*MicMac*[6], the *SfM*system *Bundler*[7,8], the*PMVS2*software for generating dense point clouds and *CMVS* for the splitting of very large files of images into smaller clusters[9,10,11], the *CMPMVS* software for reconstruction of textured MESH models from input images and parameters of interior and exterior orientation of a camera [12] or the GUI application *VisualSFM* for a 3D reconstruction of objects from images using the *SfM* method [13,14,15] and others.

It is therefore evident that nowadays there are several possibilities for image processing into the form of point cloud and subsequent digital 3D models, whether for documentation of immovable cultural heritage, archaeological artefacts, or completely different usage. However, it is questionable if such open-source software solutions are appropriate, of sufficient quality and highly accurate for image processing and generating outputs suitable for documentation of cultural heritage [16].

USED PHOTOGRAMMETRIC SOFTWARE

Based on the analysis and image processing method, the following three open-source software of the various types were selected as the most suitable:

- ***VisualSFM*** – open-source software,
- ***OSM-Bundler*** (*Bundler + CMVS/PMVS2*) – open-source software,
- ***Photosynth Toolkit*** (*Photosynth+ CMVS/PMVS2*) – web service + open-source software.

VisualSFM[13,14,15] is basically a GUI application for 3D reconstruction of objects from images using the *SfM* system into a point cloud. It is an upgraded version of author's previous projects supplemented with *siftGPU* and *Multicore Bundle Adjustment* algorithms. Moreover, this software provides an interface to run external tools like *PMVS/CMVS*, or it can prepare data for the *CMP-MVS* software.

OSM-Bundlerincludes a set of open-source tools that allow to process a 3D reconstruction of objects from images, using the *Python* programming language.

The key tools of this system are:

- *Bundler* – *SfM*system for calibration, bundle adjustment and sparse cloud reconstruction [7,8];
- *PMVS2* – generating a dense point cloud[9,10,11];
- *CMVS* – splitting of images into clusters for the rational use of computer memory, particularly for larger set of images [9,10,11].

In the last case (***Photosynth Toolkit***) [17,18], it is a combination of the web service*Photosynth*and the open-source software*CMVS/PMVS2*.Based on a set of overlapping images of an object, *Photosynth*performs a calibration, orientation of images in space and reconstruction of a given object or scene into a sparse point cloud. Subsequently, the *PMVS/CMVS* software is used to its expansion, densification and filtration into the final point cloud.

For an appropriate analysis of the output data and its comparison with regard to a certain reference data, fulfilling the criteria of sufficiently high accuracy and quality, a commercial software ***Agisoft PhotoScan***[19] chosen as the last used – reference software. ***Agisoft PhotoScan*** is a professional photogrammetry 3D reconstruction software that can automatically build highly accurate textured 3D models using digital images of the scene or object.

IMAGING METHODOLOGY

The following objects, parts of the cultural heritage monument in Slovak Republic – The Slanec castle situated in eastern Slovakia (Fig. 1), were chosen for the purposes of comparison of selected photogrammetric software in terms of their reliability, surface reconstruction quality and photo-texture quality:

- the wall of the Gothic palace,
- the southern part of the tower Nebojsa (donjon),
- the inner part of the tower window on the 3rd floor.

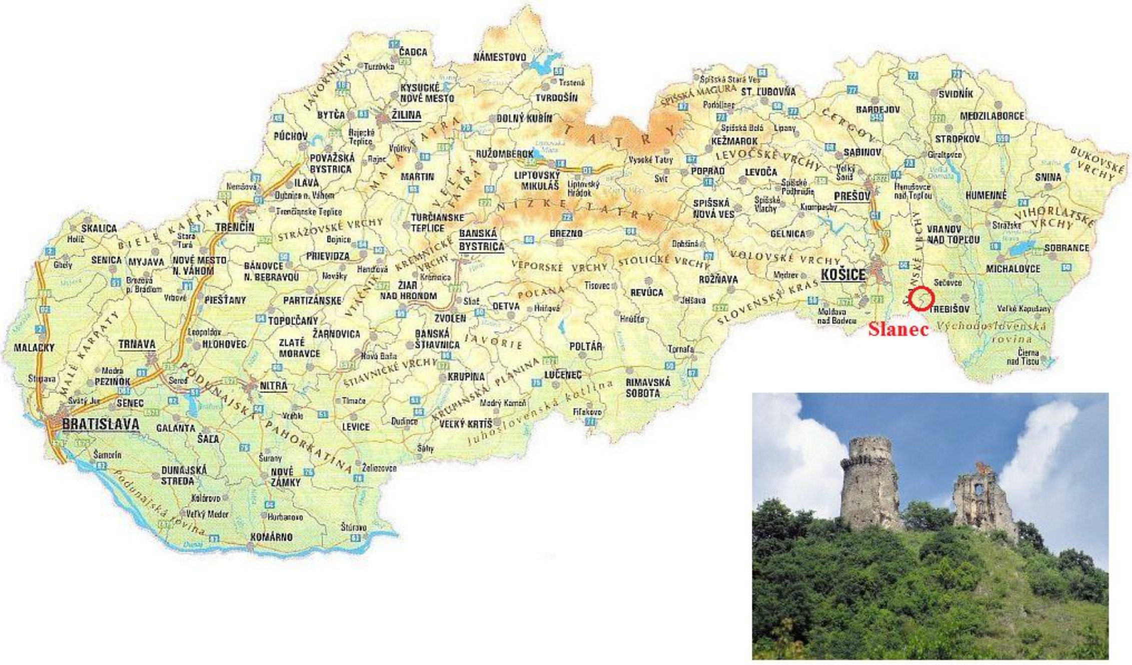

Fig. 1: The Slanec castle and its location in the Slovak Republic

All images were acquired by the DSLR*Pentax K-5*with the*SMC Pentax DA 4/15mm ED AL Limited* lens, while the calibration of digital camera was performed individually for each set of images of individual objects.For the *PhotoScan* software, it is represented by the „*Full Field Calibration*".For tested open-source software, parameters of interior orientation are determined during the processing individually for each image used (*VisualSFM*allows the use of fixed calibration for all images in the project), where each of these software determines values of the focal length and two parameters of radial distortion.

12-bit coded targets, whose spatial coordinates were determined within the geodetic survey of this cultural heritage monument [20,21], were used as ground control points for the transformation of final point clouds into the national coordinate system S-JTSK (*Datum of Uniform Trigonometric Cadastral Network*).The results of this survey, in the form of output from the commercial software *PhotoScan*, were used as reference data for the purpose of comparison of outputs from individual open-source software.

Each of these software provides certain setup options of the basic parameters affecting the quality of the final reconstruction (size of the correlation window; texture type; raster density; image resampling during processing; the number of images, in which the particular point is visible so its spatial position can be reconstructed). However, these options are not exactly the same in the case of open-source software and *PhotoScan*. In order to achieve comparable results, the same values of parameters common to all of the software were set.

Parameters of imaging and subsequent image processing are given in the Table 1.

Table 1: Parameters of imaging and image processing

	No. of images	imaging distance	GCP[1]	GSD[2]	No. of reconstructed points	m_{XYZ} [mm][3]	
the wall of the Gothic palace	50	5 - 15 m	6	3 mm	2 173 000	3,5	***Agisoft PhotoScan***
					2 056 000	3,9	***VisualSFM***
					1 403 000	4,2	***OSM-Bundler***
					1 861 000	5,0	***Photosynth Toolkit***
S part of the tower Nebojsa	20	10 - 13 m	5	3 mm	1 847 000	1,2	***Agisoft PhotoScan***
					1 580 000	0,6	***VisualSFM***
					1 515 000	1,0	***OSM-Bundler***
					1 577 000	2,7	***Photosynth Toolkit***
inner part of the window	14	3 - 5 m	5	1 mm	1 962 000	1,3	***Agisoft PhotoScan***
					1 634 000	0,5	***VisualSFM***
					1 498 000	1,1	***OSM-Bundler***
					1 662 000	1,5	***Photosynth Toolkit***

[1]*Gground Control Points*
[2] *Ground Sampling Distance -the pixel size expressed in ground (object space) units by reference to the image scale*
[3]*the overall mean error, indicates the accuracy in the reference system*

COMPARISON OF RESULTS

Point clouds – a sets of points defined by their spatial coordinates XYZ and radiometric data RGB are result of the image processing of individual castle objects by three chosen open-source software. As a first step, these outputs were compared with regard to the point cloud generated by *PhotoScan* in terms of point cloud consistency and photo-texture quality (Fig. 2 and 3).

Fig. 2: The preview of the final point clouds of the castle wall; from left – PhotoScan, VisualSFM, OSM-Bundler, Photosynth Toolkit

Fig. 3: The preview of the final point clouds of two castle objects; from left – PhotoScan, VisualSFM, OSM-Bundler, Photosynth Toolkit

Each of the software provides different results to a certain extent, in terms of the point cloud consistency and the quality of reconstruction and photo-texture. *VisualSFM* and *OSM-Bundler* provide very similar results with minimal difference for all three objects, although the output from the *VisualSFM* software contains more holes in the point cloud. On the other hand, *Photosynth Toolkit* generates the output with high quality photo-texture, but the point cloud contains a number of holes, isolated clusters of points and some parts of objects are completely missing (e.g. Fig.2 – the wall of the Gothic palace).

Apart from these open-source software, the *PhotoScan* provides stable and high-quality results while respecting appropriate conditions of imaging and configuration of imaging stations.

Important aspects, under which we can assess the suitability and usability of photogrammetric open-source software, include their controllability, speed and potential future development. The *VisualSFM* software, whose development is advancing continuously and its author works on its gradual improvement, troubleshooting and adding new functions and features, appears to be the most suitable of all three software. It also provides sufficiently detailed settings of processing parameters and calibration, relatively high processing speed (depending on hardware), reliability and a simple GUI. In contrast, *OSM-Bundler* and *Photosynth Toolkit* require additional libraries to be run, basic knowledge of the Windows command prompt and their potential future development is questionable, since the current versions of both software come from the 2010 (although for individual included algorithms, like *PMVS*, newer versions from different authors are still coming out).

As a second step, individual outputs were compared by means of relative distances and deviations between the compared point cloud and the point cloud from *PhotoScan* (Table 2). At first, the registration of compared cloud with regard to the reference cloud was performed by applying the ICP algorithm (*Iterative Closest Point*) [23]. Subsequently, values of maximum and mean distance between clouds were determined by applying a local approximation of point cloud by height function, using the *CloudCompare*software [22,23].

Tab. 2: The comparison of open-source software with respect to PhotoScan through mutual distances

	RMS_{reg} [mm][1]	σ [mm][2]	d_m[mm][3]	d_{max} [mm][4]	
the wall of the Gothic palace	5,4	3,5	1,8	44,3	***VisualSFM***
	8,1	3,9	4,6	58,1	***OSM-Bundler***
	6,5	3,6	2,8	43,9	***Photosynth Toolkit***
S part of the tower Nebojsa	4,9	2,2	1,9	32,6	***VisualSFM***
	6,2	2,5	2,6	37,2	***OSM-Bundler***
	6,9	3,9	3,3	49,5	***Photosynth Toolkit***
inner part of the window	3,1	1,3	1,2	29,4	***VisualSFM***
	4,5	2,1	2,2	25,6	***OSM-Bundler***
	4,2	1,6	1,1	59,8	***Photosynth Toolkit***

[1]*RMS (Root-Mean-Square) of point clouds registration*
[2]*standard deviation of point cloud local approximation*
[3]*mean distance between points of compared and reference cloud*
[4]*maximum distance between points of compared and reference cloud*

Parts of the table highlighted by blue colour represents the lowest values and parts highlighted by red colour the highest values achieved. Making this comparison, *Photosynth Toolkit* produces on average the highest deviations and in the case of the wall of the Gothic palace it is *OSM-Bundler* (mean or maximum distances). Conversely, the lowest deviations for all three objects are produced by *VisualSFM* (for the inner part of the window only 1,1 mm), which thus appears to be the most suitable also on the basis of this comparison.

CONCLUSION

Results of this work indicates, that each of the three open-source software utilizing the *SfM* algorithms provides different results, whether in the quality of reconstruction and photo-texture or in the degree of deviations from a reference data. *OSM-Bundler* and *Photosynth Toolkit* software provide relatively good and quality results, but their reliability is poor, which might be caused by the fact that they determine a specific set of interior orientation parameters for each used image, leading to unstable results.*VisualSFM* appears to be the most suitable open-source software, since it provides the possibility of fixed calibration, detailed settings of parameters affecting the reconstruction and reliable results when compared to other tested software. Additionally, it provided the smallest deviations (on average) from the reference model over individual steps of testing.

Of course, it is always important to take into account the required quality of data for documentation of cultural heritage. For example, different accuracy and type of outputs and documentation will be required for the assessment of object's statics (more emphasis on accuracy) as for architectural and historical research (more emphasis on the texture quality). Thus the question arises, if the comparison using mutual relative distances and deviations between point clouds (Table 2) is relevant, in the case of using open-source photogrammetric software for the needs of cultural heritage documentation, for example castle ruins, where the accuracy in *mm* does not play such an important role. However, it would be different in the case of shorter camera-to-object distances, for example reconstruction of objects small in size with rugged surface, archaeological findings, etc.

Finally, we can say that open-source photogrammetric software is among the current trends in photogrammetry. The current state of the art *SfM* algorithms began to achieve the quality of commercial photogrammetric software and even in some cases they have already achieved it. However, more detailed analysis of individual processing steps and calibration should be realized before their using in professional applications.

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