Overview of Available Open-Source Photogrammetric Software, its Use and Analysis

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Abstract

The current technological era provides a wide range of geodetic procedures and methods to document the actual state of objects on the Earth surface and at the same time course and shape of surface itself. Digital photogrammetry is one of these technologies, it allows the use of methods such as single-image photogrammetry, stereo photogrammetry (optical scanning), convergent imaging and SfM method (structure-from-motion) with final data in the form of point clouds, digital spatial models, orthophotos and other derived documents. Similar outputs can be obtained also by other technologies, mainly by terrestrial laser scanning, whilst each of the two technologies offers certain advantages and disadvantages. Especially purchasing and operating costs are one of the major drawbacks of laser scanning (while being an advantage of photogrammetry). In recent years, there has been a significant increase in development and creation of new, freely accessible (open-source) photogrammetric software, thus reducing these financial demands even more. The aim of this paper is to provide a basic overview of some of the most suitable open-source photogrammetric software and point out their strengths and weaknesses.

1. Introduction

As already outlined, terrestrial laser scanning is a very suitable technology for surveying and documentation, since it provides fast and comprehensive survey of objects, stable results, relatively easy processing of measured data and visualization of data in the form of digital 3D models. However, laser scanning has its drawbacks, such as limited mobility and laborious and more challenging data collection in terrain. Moreover, in the case of laser scanners with integrated digital cameras, which provide only low geometric and radiometric resolution, also low radiometric quality of final point cloud, or low quality of an orthophoto, can be a disadvantage. High purchase costs of hardware and software are also a major drawback of laser scanning (Fraštia, 2012).

On the contrary, in the case of photogrammetry, the documentation could be realized only by an analogue form until recently, which might not always have sufficient informative value, its storage is not practical and is subject to atmospheric effects. However, the development of digital technologies offers a wide range of such possibilities of documentation, by using which we are able to obtain quality data with high informative value, reliable information about the position of objects, about their geometrical properties and also about radiometric characteristics of their surfaces. Results of digitization, for example in the form of point clouds, vector models, TIN models, digital images of objects, etc., may represent such data. Compared to laser scanning, digital photogrammetry has many advantages – higher accuracy for shorter imaging distances (< 5 m), relatively easy data collection in terrain, high radiometric resolution of final point cloud and relatively low purchase costs (Fraštia, 2012).

In the area of computer vision and photogrammetry, a lot of effort has been spent to develop new procedures for processing photographic images into the form of digital 3D models in recent years.

2. Photogrammetric software and web services freely available

Nowadays, we already have a large number of freely available photogrammetric software, or algorithms containing sub-steps of image processing, as well as multiple web services enabling object reconstruction from images through the internet connection and remote services.

Amongst such software and web services, we can include for example *SIFT* algorithm (Lowe, 2004), which can be used to obtain characteristic scale invariant features of images that are further used to find reliable correlations between images (image matching), a system for creating 3D models from digital images (Pollefeys, 2004), *MicMac* software (Pierrot-Deseilligny, 2006), SfM system *Bundler* (Snavely 2010), based on the previous project *PhotoTourism* (Snavely, 2006), *PMVS2* software for generating dense point clouds and *CMVS* for splitting too large set of images into smaller clusters (Furukawa, 2010), *CMPMVS* software for reconstruction of textured MESH models from input images and parameters of interior and exterior orientation of camera (Jancosek, 2011) or GUI application *VisualSFM* for 3D reconstruction of objects from images using the SfM method (Wu, 2012).

In the case of web services, these are applications offering the possibility to create point clouds or directly 3D MESH models from images, often without the need of installing some additional software on a computer of the end user. Currently, there are number of them, such as *123D Catch* by *Autodesk*, *Photosynth* by *Microsoft*, *My3DScanner*, *ARC3D* and more. For some of these services (e.g. *Photosynth*, *My3DScanner*), however, a fully automated approach is a disadvantage, since it provides no possibility of intervention in the reconstruction process, no information about the accuracy of calibration, image orientation and final model, and no tools for data transformation into the reference coordinate system.

3. The current state

A multi-image orientation is one of the most important tasks in photogrammetry and 3D modelling in computer vision. The process of orientation often includes simultaneous calibration, resulting in a well-known method of self-calibration. The accuracy of image orientation and camera calibration significantly affects the quality and accuracy of all subsequent processes, such as determination of spatial coordinates of individual points or 3D modelling. Orientation and calibration are therefore basic prerequisite for multiple applications. Due to the possibility of using coded targets, both procedures are already fully automated for several years, whether for various laboratory or industrial applications.

In procedures for image orientation and camera calibration, it is important to distinguish between photogrammetry and computer vision. In photogrammetry, more emphasis is given to the accuracy of orientation and calibration with less emphasis on their automation. Since one of the major applications of computer vision are robotics and reverse engineering, where automated processing is a prerequisite, the area of computer vision focuses primarily on automation of orientation and calibration processes, often disregarding the geometric quality of results.

A basic overview of camera calibration procedures within close-range photogrammetry and computer vision was presented in the publication (Remondino and Fraser, 2006). In the area of computer vision, a full-field calibration procedure is preferred, leading to the so-called Structure-from-Motion (SfM) method, which includes simultaneous determination of parameters of interior and exterior orientation of camera and 3D structure captured in images. Automatic image orientation procedures without the use of coded targets have been available for several years in the area of photogrammetry, but the greatest development and innovation of these procedures originate from computer vision approximately since the late 90s, together with the SfM method.

Reconstructions based on this method were generally useful mainly for visualization purposes and not for photogrammetry and mapping. Nowadays, due to advances in computer technology and computer performance, also large number of images may already be automatically oriented in arbitrarily defined coordinate system by using different algorithms, often available as open-source software (*VisualSFM*, *Bundler*, *PMVS2*, *CMVS*, etc.) or in the form of web services (*Microsoft Photosynth*, *Autodesk 123D Catch*, *My3DScanner*, etc.). Automation of individual processes and procedures based on the image processing through the internet basically help to save human resources in data processing, but on the other hand, they provide no guarantees regarding the quality of 3D models and safety of private data. Therefore, it is important to obtain assessment of the accuracy and reliability of such automated procedures, which would also certainly help layman dealing with a 3D reconstruction form digital images.

4. Software selection

In today's computer-internet age, large number of freely available tools or tools limited in varying degrees, allowing to process different types of photographic images, is available in addition to standard commercial photogrammetric software. However, not all of them can be used to create sufficiently accurate and high-quality documents, either for further processing in different software or directly in the form of outputs necessary for documentation.
On the other hand, professional commercial photogrammetric software are reliable tool for the creation of such data and their quality has already been verified by large number of surveyors as well as experts from other scientific fields and practice, during the period of their availability. The following open-source software and web services of different types were selected for the purpose of this paper:

- ***VisualSFM*** – open-source software [32],
- ***OSM Bundler*** (*Bundler* + *CMVS/PMVS2*) – open-source software [7,8,9,27],
- ***Microsoft Photosynth*** – web service [20],
- ***Photosynth Toolkit*** (*Photosynth* + *CMVS/PMVS2*) – web service + open-source software,
- ***Autodesk 123D Catch*** – web service.

In addition to these selected, also large number of others exists, but they were not included in this paper for various reasons. For example, 3Defining software (does not enable direct transformation of data into user defined coordinate system), ***SFMToolkit*** software (requires a specific computer hardware – *nVidia* 3D graphic card), ***CMP-MVS*** software (requires a specific computer hardware supporting *nVidia CUDA* parallel computing architecture), ***ARC 3D Webservice*** (applicable for non-commercial purposes only), ***My3DScanner*** web service (does not enable direct transformation of data into user defined coordinate system) and more.

4.1. VisualSFM

VisualSFM (Fig. 1) is a GUI application for 3D reconstruction of objects from images using the SfM system. *Changchang Wu* is the author of this software. Basically, it is an upgraded version of his previous projects that is complemented by *SiftGPU* and *Multicore Bundle Adjustment* algorithms. Moreover, this software provides an interface to run tools like *PMVS/CMVS*, resp. it is able to prepare data for *CMP-MVS* software.

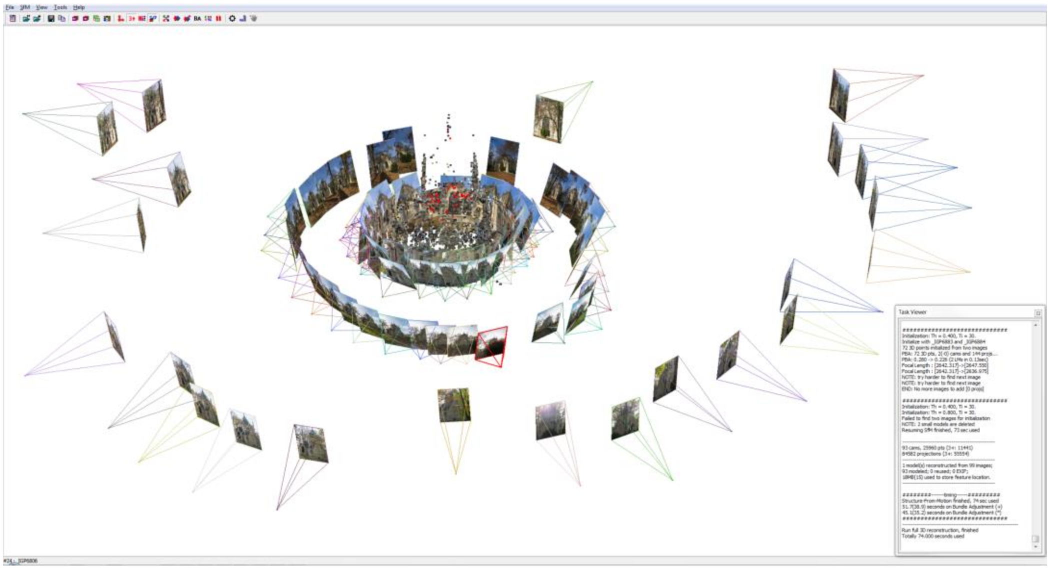

Figure 1: VisualSFM – working interface

Reconstruction of objects from images using *VisualSFM* consists of the following steps:

1. open images in the SFM workplace – either through menu or by corresponding panel buttons;
2. run detection of image features and searching correlations between images (matching);
3. run sparse reconstruction – i.e. bundle adjustment and creation of sparse point cloud;
4. dense reconstruction using *CMVS/PMVS* – individual parameters affecting the reconstruction can be find in the nv.ini file that is automatically generated on the first start of software, in its main directory.

The software provides a wide range of settings, by which we can modify the reconstruction process. For example, the change of maximum used resolution of images, with which the *SiftGPU* [31] algorithm will work; specification of user's own list of image pairs for image matching; direct use of custom list of image features; use of custom feature detectors instead of *SiftGPU*; and more.

4.2. OSM-Bundler

OSM-Bundler (Fig. 2) is a set of open-source tools that allow to run 3D reconstruction of objects from images, using the Python programming language.

Key tools of this system include:

- *Bundler* – calibration, bundle adjustment and reconstruction of sparse point cloud (Snavely, 2012);
- *PMVS2* – densification of point cloud; *Yasutaka Furukawa* is its author (Furukawa, 2010);
- *CMVS* – splitting images into smaller clusters for rational use of computer memory, especially for larger set of images; *Yasutaka Furukawa* is its author (Furukawa, 2010);

To obtain image features, the algorithms *SIFT* [18] or *sift++* [29] are included in this toolkit and can be used.

Bundler is a SfM system for processing unordered sets of images, originally compiled in C and C++. The previous version of this SfM system was used in the *PhotoTourism* project (Snavely et al., 2006).

A set of images, image features and matches between these features represents input data for Bundler, which subsequently creates a sparse 3D reconstruction of geometry of cameras and the whole scene captured in images as output. This system reconstructs scenes incrementally, simultaneously after several images, using the modified version of the *SBA - Sparse Bundle Adjustment* (Lourakis, 2009).

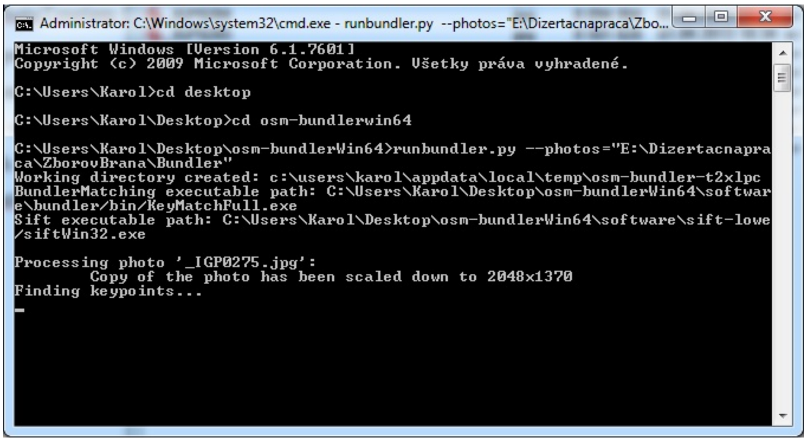

Figure 2: The use of OSM-Bundler – Bundler + PMVS2

4.3. Microsoft Photosynth

Microsoft Photosynth (Fig. 3) is a free online tool that automatically combines a set of images capturing the same scene into a single interactive 3D output, which can be shared directly through this service with anyone on the internet. Basically, Photosynth provides two tools to create 3D outputs.

One of these, which clearly defines this product, is a tool called „*synth*“. Synth is basically a set of overlapping images of a specific object or scene that was automatically reconstructed to a spatial model. The process that generates this model uses the principle of natural stereoscopic vision and algorithms similar to those used by the *OSM-Bundler* toolkit (*SIFT*, *Bundler*). However, a detailed description of used algorithms is not publicly available. This tool is able to reconstruct a scene captured in 200 images in about 5-10 minutes on an average computer. The length of reconstruction depends on several factors: image resolution, number of images, their optical quality (sharpness, exposure), and method of imaging the reconstructed scene.

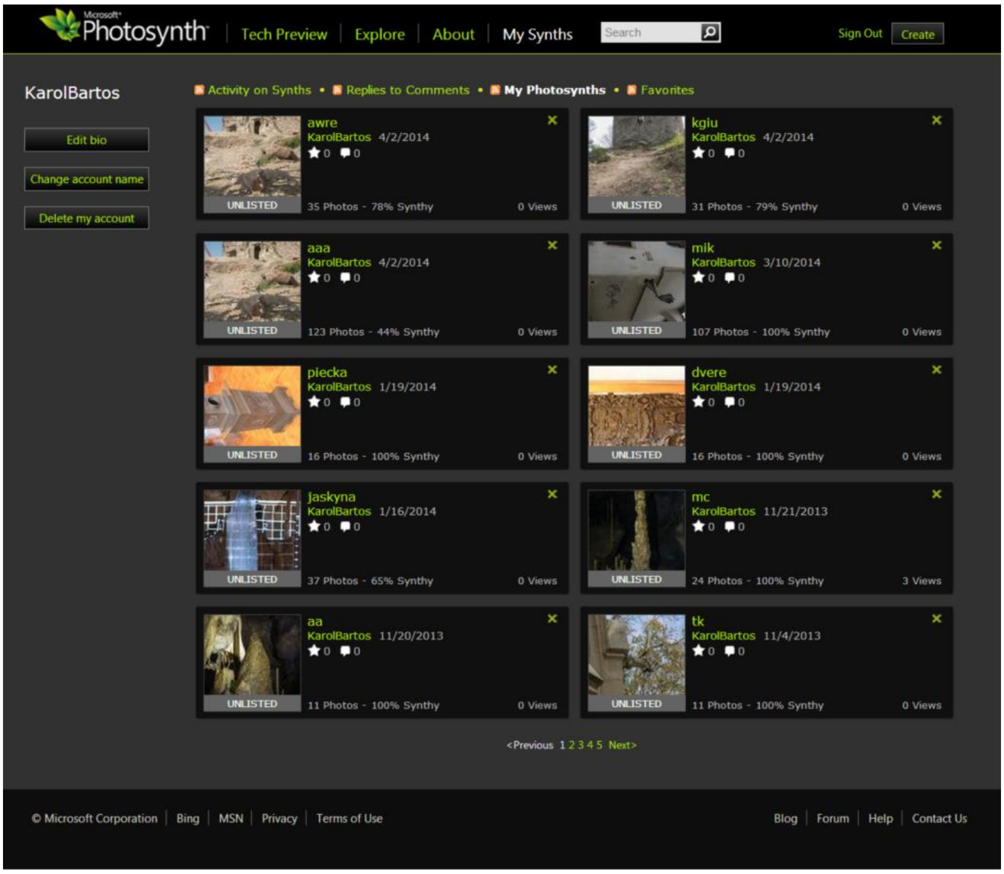

Figure 3: Microsoft Photosynth

The main drawback of this service is the fact that it does not allow direct download of data to a computer. It means that they are only available via the internet. [39]

4.4. Photosynth Toolkit

Photosynth Toolkit is an open-source software that can be used to create a dense point cloud from images that have already been processed through *Photosynth* web service.

Four simple windows scripts that guide the user from downloading data from the Photosynth to the creation of dense point cloud are the main principle of this software:

1. *Download Synth*;
2. *Watch Photosynth output* – if necessary, the user can view downloaded data through *Ogre3D Photosynth viewer*;
3. *Prepare for PMVS2* – preparation of downloaded data for their processing by *PMVS2*;
4. *Prepare for CMVS* – preparation of data for *CMVS*. [2]

4.5. Autodesk 123D Catch

The *123D Catch* web service (Fig. 4) by *Autodesk* is a tool very similar to the *Microsoft Photosynth*. It is also a freely available service that allows to generate a digital spatial model from images capturing an object or scene from different positions. As with *Photosynth*, detailed descriptions of algorithms and procedures of image processing are not publicly available even in this case. However, processing undoubtedly involves the use of SfM method with an initial identification of common image features using an algorithm similar to *SIFT* algorithm. Subsequently, the bundle adjustment and determination of parameters of interior and exterior orientation is performed and finally a MESH model representing the object is generated. This service has evolved from the previous project *Autodesk Photofly*, initially available in 2010.

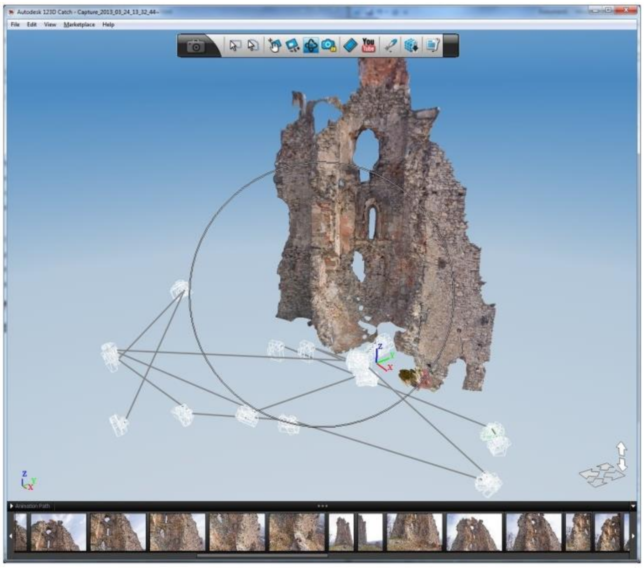

Figure 4: Autodesk 123D Catch

The method of representation of the final model is a significant difference in comparison with *Photosynth* - *123D Catch* generates a MESH digital model in contrast to point cloud. One can edit this model, delete unwanted parts, create and export video animations, define reference points, lines or distances in images and thus on the model, define reference distance and coordinate system directly in the application. The quality of

MESH model (mobile, standard, maximum) is an important option that the application provides and it should be taken into account.

6. Comparison of software

Point clouds – sets of points defined by their spatial coordinates XYZ and radiometric data RGB are result of image processing of individual objects using selected open-source software. These outputs can be compared in terms of reconstruction density, point cloud consistency and quality of photo-texture (Fig. 5).
Microsoft Photosynth web service provides output of poor quality – point cloud contains many outliers and is too sparse, which also implies the quality of the photo-texture that would be of low quality in case of further processing (for example to a MESH model). *OSM-Bundler* software provides denser reconstruction with less noise and higher quality photo-texture, however the point cloud is not uniform and contains a number of small holes. Sufficiently dense point cloud is result of the processing with *VisualSFM* software, it can deal with the material texture in a better way – the point cloud is uniform and contains a minimum of holes. *Photosynth Toolkit* software and *Autodesk 123D Catch* web service provide sufficiently dense reconstruction with low noise (*Ph. Toolkit* contains slightly more noise), without holes. In both cases, outputs dispose high quality photo-texture that is slightly worse in the case of *123D Catch*. The biggest disadvantage of this service is the fact that quality of photo-texture can be different for every reconstruction of the model from the same images. One could say that it is random, resulting in the fact that before the image processing, user can never be sure whether the resulting model will be usable for further work.

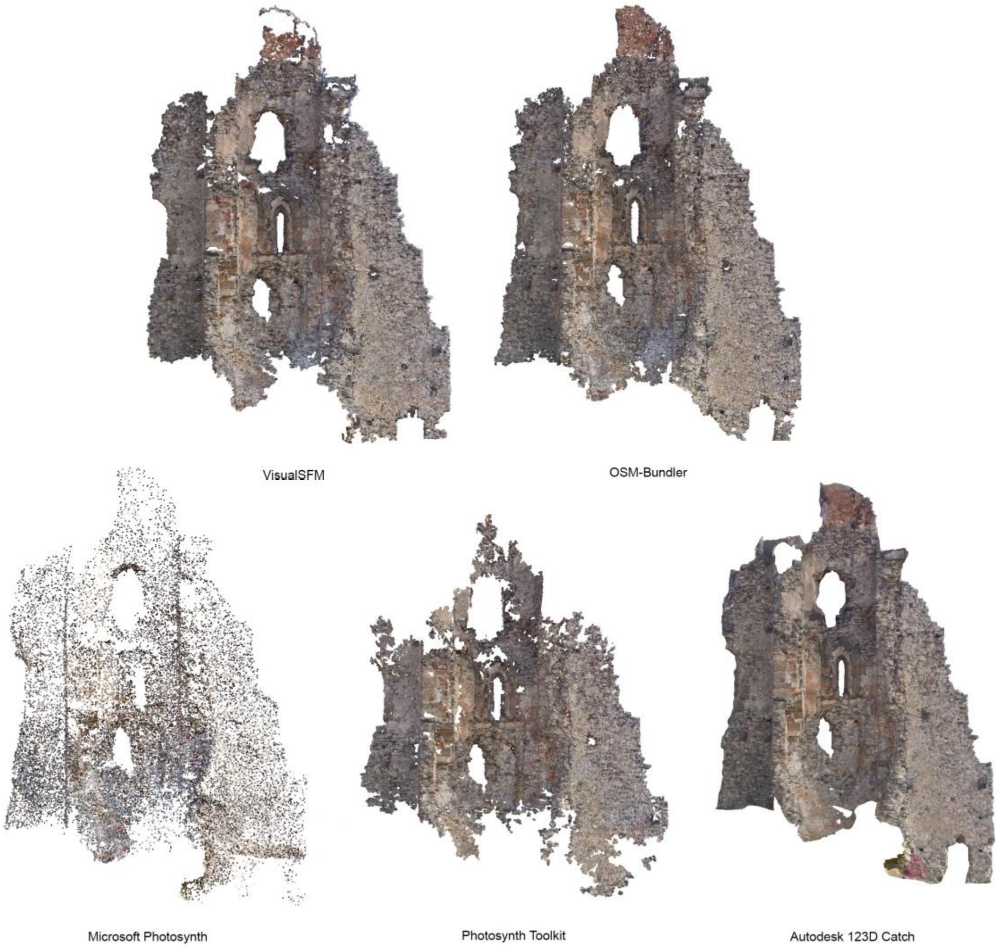

Figure 5: Example of point clouds created from images of object of historical monument using each of tested software [4]

Other significant aspects, on which one can assess the suitability and usability of open-source software, include their controllability, speed and further potential development. *VisualSFM* software seems to be the most suitable of all, its development is progressing constantly and its author is working on progressive improvement, troubleshooting and adding new features. It also provides sufficiently detailed settings of processing and calibration parameters, relatively high speed of processing (depending on hardware), reliability and simple graphical user interface. In contrast, *OSM-Bundler* and *Photosynth Toolkit* requires additional libraries to be run, the knowledge of the command prompt in OS Windows and their further potential development is questionable, since current versions of both software come from 2010 (although for different algorithms included, for example *PMVS*, newer versions by different authors are appearing).

7. Conclusion

The use of low-cost solutions and open-source photogrammetric software, whose fundamental principle is the SfM method of surface reconstruction, is among the latest trends in the area of photogrammetry. Initially, they were developed in computer vision, but they are slowly finding their application also in photogrammetry, whether for documentation of cultural heritage, but also for the acquisition of topographic data and other applications. To obtain high quality results, it is necessary that the software used meets certain criteria regarding the accuracy of calibration, image orientation and dense surface reconstruction.

It turns out that not every one of such software is suitable for use in professional photogrammetric applications. *VisualSFM* software appears to be the most suitable for the needs of survey documentation, as well as for, for example, teaching of photogrammetry. In contrast to others, it provides the possibility of using a single, fixed calibration, detailed settings of parameters affecting the reconstruction and reliable results.

In conclusion, one can say that the current state-of-the-art SfM algorithms began to achieve the quality of commercial photogrammetric software and in some cases, they have already achieve it. However, before their use for the purpose of survey documentation, more detailed analysis of individual processing steps would be necessary and especially improvement of camera calibration, thereby improving their accuracy and reconstruction quality.

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