3D RECONSTRUCTION OF MINING HARVESTER HEAD USING MULTI-VIEW PHOTO

David Hoffmann, Petr Hermanek, Adolf Rybka, Ivo Honzik
Czech University of Life Sciences Prague
dhoffmann@tf.czu.cz

Abstract. Use of 3D reconstruction of objects and modeling for 3D remodeling of cultural heritage has become common. 3D reconstructions of objects (e.g., agricultural prototype) are more and more frequently employed in several disciplines such as medicine, CAD tools, archeology, engineering, etc. The capability of performing accurate analyses directly on a 3D model allows for a significant improvement in the accuracy of the analysis (measurements). The article shows a new method through the development of PW (Photogrammetry Workbench), which could be useful for architectural modeling. Traditional modeling in 3D using point clouds from laser measurement is time consuming and can be costly. Photogrammetry is one of the most cost-effective approaches we could use, because data can be collected using a basic digital photo camera. In this work we present a new methodology for 3D reconstruction of objects based on sequence multi-view photo images (2D). Photo images contain standard depth of field. The study also introduced a 3D model creation process; its modification and publishing to Cloud enable real interactive 3D model presentation shown in Web Browser. The presented tool enables the user to turn images into scale 3D point cloud models. The point clouds may include the respective orthophotos with photographic texture. During the research a mining harvester head was created as a part of another project engaged in design of a prototype of the new machine. The article compares different resolution measured shots when it turns out that the best resolution in terms of the accuracy of the calculated model and the size of the individual image is 8 Mpx.

Keywords: image reconstruction, photogrammetry, virtual parametric model, 3D model presentation.

Introduction

Photogrammetry is continuously growing in popularity among experts as well as non-experts. It is a serious competitor of laser sensors, Terrestrial Laser Scanners (TLS), Airborne Laser Scanners (ALS), or the static and dynamic MLM systems (Mobile LiDAR Mapping System) [1; 2].

The described technology of image reconstruction has two main advantages. Firstly, taking photos results in 3D dense point cloud. This has, in some cases, a higher resolution compared to the data from laser scanners. Secondly, there is a large flexibility in equipment for image capture which can be further uploaded to photogrammetric programs. In the past years, various types of equipment are possible to employ to record images, such as cameras (both calibrated and non-calibrated) [3; 4], mobile phones or tablets [5]. Photogrammetry offers another advantage, which is accuracy and reliability of the measured results [6; 7].

The technology of photogrammetry managed to solve the problems of imaging which does not need to be done in laboratory conditions anymore. However, it is still necessary to ensure places for taking photographs and well-planned reference points needed for image stitching (a function based on comparing similar image points).

At present, several open source and commercial programs for photogrammetry are available, such as, e.g., eATE, NGATE, Dense Matcher, ISAE, Match-T, Xpro, Tridicon, PhotoScan, etc. [8]. All the programs operate on the principle of creating 3D point clouds by reconstructing more images by employing slanting and converging geometry [9; 10]. Other internet tools include 123D Catch, Bundler, Photosynth, or, e.g., Photofly Insight 3D. These programs are based on the principle of algorithms visible for the computer and calculate the photo orientation by means of an independent model. The main disadvantage of the presented programs resides in the fact that the camera inner parameters and the surroundings of the object captured by the camera directly influence the quality of the reconstructed 3D object.

The paper presents one of the freely accessible photogrammetric cloud programs Autodesk Recap 360. It serves as an example to describe the way of eliminating the above mentioned disadvantages, which influence directly the quality of the final 3D model. The online Autodesk Recap 360 program is applied widely in architecture, mechanical engineering, agricultural production, modern medicine, etc.

The paper introduces in detail the method of model reconstruction by the method of photogrammetry, in which the technology is applied to create a model of the operating part of the harvester head for logging.

Materials and methods

The workflow applied for creation of a 3D model using the method of photogrammetry consists of several steps. These are carried out automatically, semi-automatically or manually. Semi-automatic processing operations relate to the reconstruction of a 3D model from photos, when the calculation itself is fully automated, but the setting of the program's marginal conditions (or reference points) is provided by the user. The operations related to recording the photos, their adjustment, or also to the final adjustment of the obtained 3D model are most often manually processed.

As mentioned above, the key step in a correct reconstruction of a 3D model is data collecting in the form of images. CIPA (Comite International de Photogrammetrie Architectural) laid down 3x3 rules for suitable data collecting of a simple photogrammetric documentation of architecture [11]. Although the quality of cameras and videocameras and correspondingly the final photo quality have been improving now, the CIPA rule is recommended to be reformulated, regarding the higher number of the required captured images. In case of capturing a complicated part in terms of its shape, even greater amount of photos is required, compared to, e.g., imaging of architectural monument surfaces.

The measurements were carried out on a harvester logging head (Figure 1) and the aim of the measurement was to create its 3D model by means of the photometric method.

Field measurement

The object of this measurement was to create a sufficient photographic documentation of the harvester head, to reconstruct its 3D model which would serve for purposes of a design for placing tensometric sensors in the next project.

Imaging was carried out by means of Canon EOS 7D DSLR camera. Due to bad light conditions at the time of shooting (clouds + gloom in the forest spruce stand) the image resolution was set to 16 Mpx. The object was photographed by two ring networks. Each of these networks consists of 31 images, which corresponds approximately to an angle of 11.6º, included by normal axes of two neighbouring images. The ring networks were captured at a distance of 700 and 1400 mm above the surface of the surrounding terrain.

The independent network maps in detail show only parts of the logging head and consist of 24 images. To reconstruct the 3D model of the harvester logging head we used altogether 24 images.

Fig. 1. **Photographed logging head of harvester**

Laboratory post-production

For purposes of creating the 3D model of the logging head we used the Autodesk Recap 360 program with cloud storage. After the batch image editing, resulting in contrast and image colour modification, the images were uploaded to the internet cloud. Therefore, the calculation of the 3D model is not processed on a local computer, but on the Autodesk high-performance servers.

Recap 360 enables an online check by viewing the reconstructed 3D model, in which you can add other photos, thus making the model more accurate. The resulting 3D model to check is depicted in Figure 2.

Laboratory measurement

The object of the laboratory measurement was to find out experimentally which is the minimum image resolution suitable for 3D model reconstruction at such accuracy where the delimbing knives would be generated. The experiment aim was to discover what influence the image resolution has on the final 3D model generation.

First, 24 photos had been selected for the model reconstruction, captured by the ring method, which are sufficient for the 3D model reconstruction. Afterwards, these photos were copied into six files. Each file contains edited photos with different resolution: 16, 12, 8, 4.5, 2.5 and 0.3 Mpx.

Then from each series of image resolution a 3D model was generated. Individually generated models were compared from the following viewpoints:

1. Amount of points in the created dense cloud,
2. Amount of surfaces defining the 3D model surface,
3. Total data size of the image series,
4. Subjective evaluation of usability of the generated 3D model.

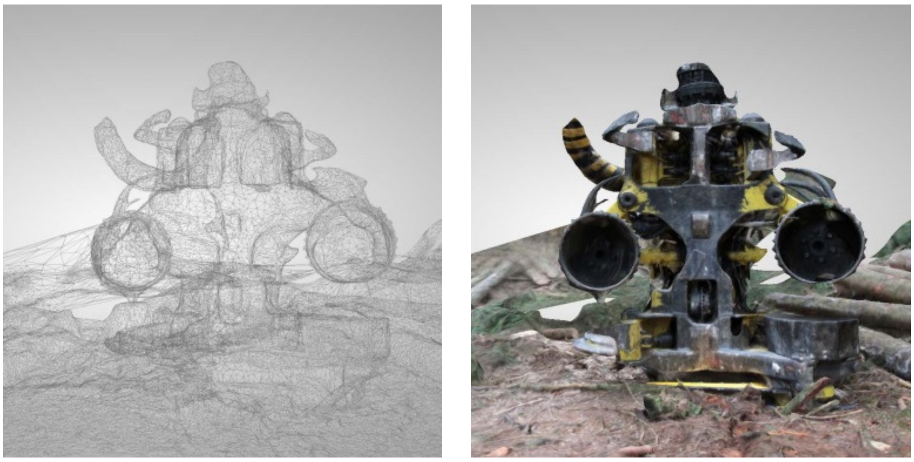

Fig. 2. **Reconstructed 3D model of harvester logging head:** left image – mesh model; right image – model with photorealistic surface

Results and discussion

Reconstruction of harvester logging head

Individual dense cloud points were interconnected by polygons into a mesh creating the 3D model surface (surface consists of 773600 planes). Not only the 3D model of the logging head was generated, but also the 3D model of its immediate surroundings was generated which is formed by the above mentioned reference points.

The resulting 3D model (Figure 3) of the logging head together with the immediate surroundings consists of 677055 surfaces and 338955 vertices (points).

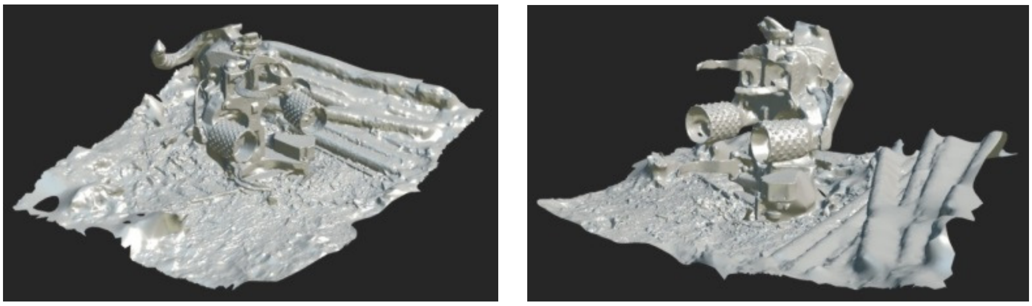

Fig. 3. **Resulting model without photorealistic surface** (different views) – available at the address **p3d.in/s2aFs**

Laboratory measurement

After the 3D models had been generated, their vertices and planes forming the surface were calculated. Further items to be recorded were the total data size of the given image series, and the data size of the reconstructed *.obj file. The figures collected are listed in Table 1.

After the reconstruction of the 3D models had been completed, it was found that the models composed of images with resolutions of 16, 12 and 8 Mpx are suitable for further use. Figure 3 displays an example demonstrating the resulting reconstruction of the 3D model of the harvester logging head, composed of 24 photos with resolution of 12 Mpx.

The models composed of images with resolution of 4.5, 2.5 and 0.3 Mpx proved to be unsuitable for subsequent usage in the structure. From these images the photogrammetric program could not definitely distinguish the background from the reconstructed object, therefore they merged.

The graph (Figure 4) displays graphic dependency of the number of the 3D cloud points, of the number of the model surface planes and of the total data size on the number of the image points. The graph clearly shows that the photos with 12 Mpx resolution offer the best ratio between the data image size and the number of the reconstructed 3D cloud points.

Table 1

Measured numbers of 3D cloud points and number of surface planes.

Measurement No.	Image point No.	Photo resolution, px	3D cloud point No	Surface plane No	Total photo data size, MB	*.obj file size, MB
1	16 Mpx	5184 x 3456	497900	994200	233	61.8
2	12 Mpx	4000 x 3000	292900	584800	93.5	45.3
3	8 Mpx	3456 x 2304	164300	327800	73.3	25.4
4	4.5 Mpx	2592 x 1728	58300	116300	45.9	8.7
5	2.5 Mpx	1920 x 1280	35700	71000	28.1	5.3
6	0.3 Mpx	720 x 480	6100	12000	5.46	0.8

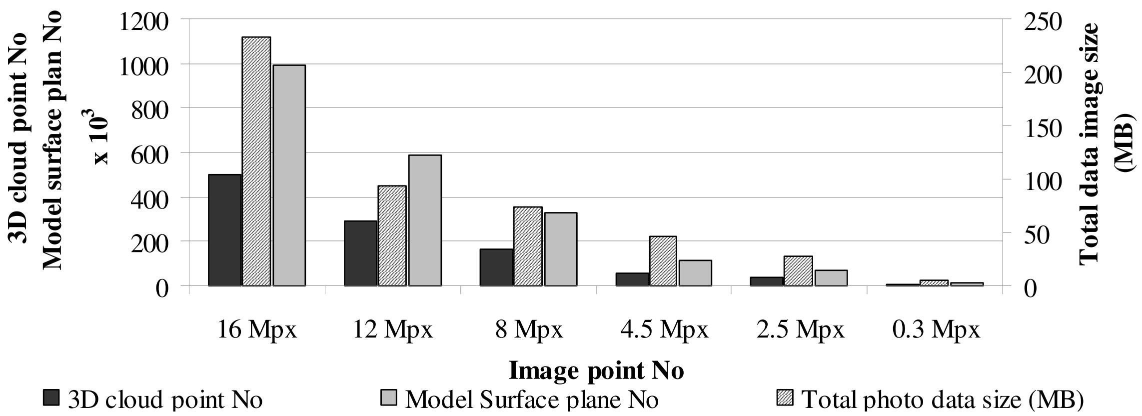

Fig. 4. **Graphic dependency of number of 3D cloud points, number of model surface planes and total data image size on number of image points**

Conclusions

The conclusions should not just restate the main results but draw wider conclusions from the results. It may include bulleted items.

The paper presents the technology of photogrammetry, which was in this case applied to reconstruct the 3D model of a harvester logging head. Owing to a relatively simple workflow, whether referring to capturing photographs, their processing, or subsequent 3D model reconstruction, it enables to obtain accurate graphic results.

The following conclusion can be drawn from the field measurement:

1. The imaging time (of the harvester head in this case) was 30 min in the field and 7 hours in the laboratory (including the calculation time of the cloud server). Compared to the laser scanner (TLS) performance, the data collecting for purposes of the photogrammetric method is by ½ up to ⅔ faster depending on the TLS performance. The laboratory time of data processing is similar [8]. For this reason (comparing the initial investment) the method of photogrammetry is more favourable.

2. Due to a large number of photos (and correspondingly to a large number of connecting reference points), the photogrammetric method ensures a precise placement of neighbouring images. To reconstruct the model required 338.955 points, which were further connected into planes forming the 3D model surface.
3. Gago et al. (2014) recommend taking during one series of shooting through the ring method 24 images, corresponding to an angle of 15º. Practice proved that this number is insufficient with more complicated shapes, and programs were able to reconstruct a plane from 30 photos and more.

From the laboratory experiment trying to find the most suitable image resolution we may draw the following conclusion:

1. The most suitable images for 3D model reconstruction are those with a resolution higher than 8 Mpx.
2. The most suitable images to be applied in the photogrammetric method are those with a resolution of 12 Mpx, at which the best ratio of the image data size and number of reconstructed 3D model points is ensured.

In the future, it would be appropriate to create methodology for the usage of the photogrammetric method, which would help inexperienced users to position the capturing camera in the right way and secure suitable parameters for imaging.

Acknowledgements

This article was written as part of a research project GA TF 2014:31160/1312/3119 and TECHNOLOGY AGENCY OF THE CZECH REPUBLIC TA 04031250.

References

1. Haala N., Peter M., Kremer J., Hunter G. Mobile lidar mapping for 3D point cloud collection in urban areas – A performance test. Int. Arch. Photogramm. Remote Sens. Spat. Inf. Sci., 37, 2008, pp. 1119-1127.
2. Quan L. Image-Based Modeling; Springer: New York, NY, USA, 2010.
3. Liu G.H., Liu X.Y., Feng Q.Y. High-accuracy three-dimensional shape acquisition of a large-scale object from multiple uncalibrated camera views. Appl. Opt., 50, 2011, pp. 3691-3702.
4. Gruen A., Akca D. Mobile Photogrammetry. In Dreiländertagung SGPBF, DGPF und OVG; In Proceedings of 2007 Wissenschaftlich-Technische Jahrestagung der DGPF, Muttenz, Basel, 19–21 June 2007; Volume 16, 2007, pp. 441-451.
5. Kraus K. Photogrammetry. Fundamentals and Standard Processes; Dummlers Verlag: Bonn, Germany, Volume 1, 1993.
6. Arias P., Caamano J.C., Lorenzo H., Armesto J. 3D modeling and section properties of ancient irregular timber structures by means of digital photogrammetry. MICE Comput.-Aided Civ. Infrastruct. Eng., 22, 2007, pp. 597-611.
7. Lorenzo H., Arias P. A methodology for rapid archaeological site documentation using ground-penetrating radar and terrestrial photogrammetry. Geoarchaeology, 20, 2005, pp. 521-535.
8. Gago J.G., Aguilera D.G., Lahoz J.G., Alonso J.I.S.J. A Photogrammetric and Computer Vision-Based Approach for Automated 3D Architectural Modeling and Its Typological Analysis. Remote Sens., 6, 2014, pp. 5671-5691.
9. Seitz S.M., Curless B., Diebel J., Scharstein D., Szeliski R.A. Comparison and Evaluation of Multi-View Stereo Reconstruction Algorithms. In Proceedings of the 2006 IEEE Computer Society Conference on Computer Vision and Pattern Recognition, Washington, DC, USA, 17-22 June 2006; Volume 1, 2006, pp. 519-528.
10. Furukawa Y., Ponce J. Accurate, dense, and robust multiview stereopsis. IEEE Trans. Pattern Anal. Mach. Intell, 32, 2010, pp. 1362-1376.
11. Patias P., Santana Quintero M. Introduction to Heritage Documentation. In CIPA Heritage Documentation Best Practices and Applications; The ICOMOS & ISPRS Committee for Documentation of Cultural Heritage: Athens, Greece; Volume XXXVIII-5/C19, 2011, pp. 9-13.