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Study on 3D Point Clouds Accuracy of Elongated Object Reconstruction in Close Range – Comparison of Different Software

Grzegorz Gabara[1], Piotr Sawicki[2]

Department of Photogrammetry and Remote Sensing, University of Warmia and Mazury in Olsztyn, Poland
E-mails: [1]grzegorz.gabara@uwm.edu.pl; [2]piotr.sawicki@uwm.edu.pl

Abstract. The image based point clouds generated from multiple different oriented photos enable 3D object reconstruction in a variety spectrum of close range applications. The paper presents the results of testing the accuracy the image based point clouds generated in disadvantageous conditions of digital photogrammetric data processing. The subject of the study was a long shaped object, i.e. the horizontal and rectilinear section of the railway track. DSLR Nikon D5100 camera, 16MP, equipped with the zoom lens (f = 18 ÷ 55mm), was used to acquire the block of terrestrial convergent and very oblique photos at different scales, with the full longitudinal overlap. The point clouds generated from digital images, automatic determination of the interior orientation parameters, the spatial orientation of photos and 3D distribution of discrete points were obtained using the successively tested software: RealityCapture, Photoscan, VisualSFM+SURE and iWitness+SURE. The dense point clouds of the test object generated with the use of RealityCapture and PhotoScan applications were filtered using MeshLab application. The geometric parameters of test object were determined by means of CloudCompare software. The image based dense point clouds allow, in the case of disadvantageous conditions of photogrammetric digital data processing, to determine the geometric parameters of a close range elongated object with the high accuracy ($m_{XYZ} < 1$ mm).

Keywords: digital image, matching, point cloud, 3D object reconstruction, close range.

Conference topic: Technologies of geodesy and cadastre.

Introduction

The 3D reconstruction of scenes and objects in close range is generally performed based on dense point clouds in a variety spectrum of applications, such as industrial, civil, medical engineering, biomechanics and robotics, mobile mapping, cultural heritage, etc. Dense point cloud may be obtained by active (range data) and passive (image data) sensors. Laser scanners or structured light systems are source of range data, whereas image data are obtained by means of optical systems (Vosselman, Mass 2010). New image processing possibilities have been recently created by the, so-called, photogrammetric scanning method, basing on point clouds generated from sequences of digital images. The image-based approach requires the use of a large set of multiple different, mainly oblique and convergent oriented photos and is presently offering automated procedures for interior and spatial image orientation and complex 3D reconstruction, modelling and visualization. Dense point cloud generation (dense image matching) is implemented in various low-cost and open-source as well as commercial software. The multi-view stereo (MVS) method using a semi-global matching (SGM) type of stereo algorithm is mostly used for dense image matching.

Image based 3D modelling and surveying has recently become important due to the progress and new developments in algorithms and automated procedures using photogrammetric methods. The dense point clouds and advanced data processing allow to recognise and completely reconstruct 3D objects and then to measure and extract geometric and semantic information. The further progress in dense image matching (the photogrammetric scanning method) is among others connected with development of new algorithms, filtering, feature extraction, segmentation and classification and with development of methodologies for the praxis (ISPRS 2017). An important task and research problem is also testing the accuracy of point clouds generation and processing for 3D surface reconstruction in various close range applications.

The aim of the performed research works was to test the accuracy of generation and processing image-based point clouds in inconvenient conditions of photogrammetric digital works, e.g.:

- A small, flat, elongated and horizontally oriented close range object.
- Disadvantageous configuration of photos (oblique photos with the image plane inclined under a small angle to the normal).
- Control points located on a quasi one plane.
- Use of non-metric, medium-resolution digital SLR camera.
- Difficult geometric and radiometric conditions of digital multi image matching.

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Test object and digital image acquisition

The test object was the horizontal and rectilinear section of the railway track of approx. 3 m length. Railway tracks are 3D elongated objects which consist of elements with cross sections similar to Double T-Bar (DTB). Six black & white and six black & red signalled control points were mounted on each rail head in 2-2-2 groups. Depending on the local scale of imaging the diameter of control points on the images varied between 6 and 19 pixels. Distances between control points were geodetically measured with the accuracy m_{XY} = 0.5 mm. Elevations of control points were determined using the precise levelling with the accuracy m_Z = 0.1 mm. Additionally, two basic geometric parameters of the rectilinear railway track section: the track gauge and the cant were measured using the hand track gauge and a cant measuring device Sola SW-9182.

The digital SLR Nikon D5100 camera, equipped with the CMOS sensor (23.6×15.6 mm size, resolution 4928×3264, the pixel size p'_{xy} = 4.8 μm) and the lens with optical stability (variable focal length f = 18÷55 mm), focused (focal f = 18 mm) on the imaging distance approx. Y_F = 2.0 m, were used to acquire photos (Fig. 1).

The datasets adopted for testing include the block of terrestrial photos, acquired with convergent and very oblique photos at different scales and with the same resolution (Fig. 1). Photos were acquired from the low height, optical axes of a digital camera were inclined under the sharp angle of about 30° in relation to the reconstructed surface of railway tracks. As a result, matching conditions were highly disadvantageous since the different local scale of projected elements and homologous details of the test object occurred in images together with high geometric deformations of the image structure and texture. Additionally, the surface of rail heads were characterised by the amorphous texture.

Fig. 1. Configuration of 5 terrestrial oblique – convergent photos in one example strip of the tested object (source: own elaboration)

In conclusion, the performed research works were characterised by the following real conditions of photogrammetric acquisition and digital image processing:

- Long shaped objects.
- Configuration of 25 photos in 5 strips (5 photos in each strip) (Fig. 1).
- Multiple convergent and steep oblique photos recorded from low heights.
- Short focal length of the wide-angle camera lens.
- Full longitudinal overlap (Fig. 2).
- Low base/distance ratio υ.
- Use of a reference system with 6 control points (m_{XY} = 0.5 mm, m_Z = 0.1 mm).
- Self-calibration of DSLR Nikon D5100 camera 16 MP.
- Weather and light conditions dependent image acquisition.

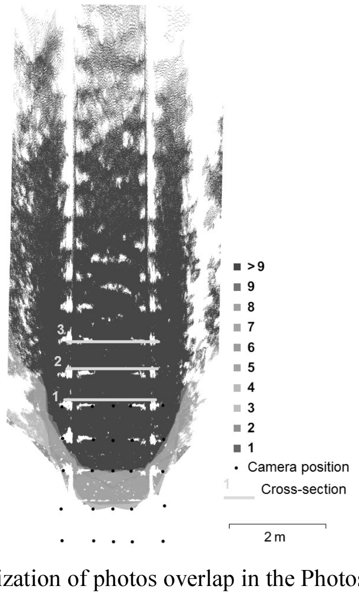

Fig. 2. Visualization of photos overlap in the Photoscan software, the camera position and cross-sections location in the test (source: own elaboration)

The performed measurements and advanced digital processing workflow of the block of photos used for the test are presented in Figure 3.

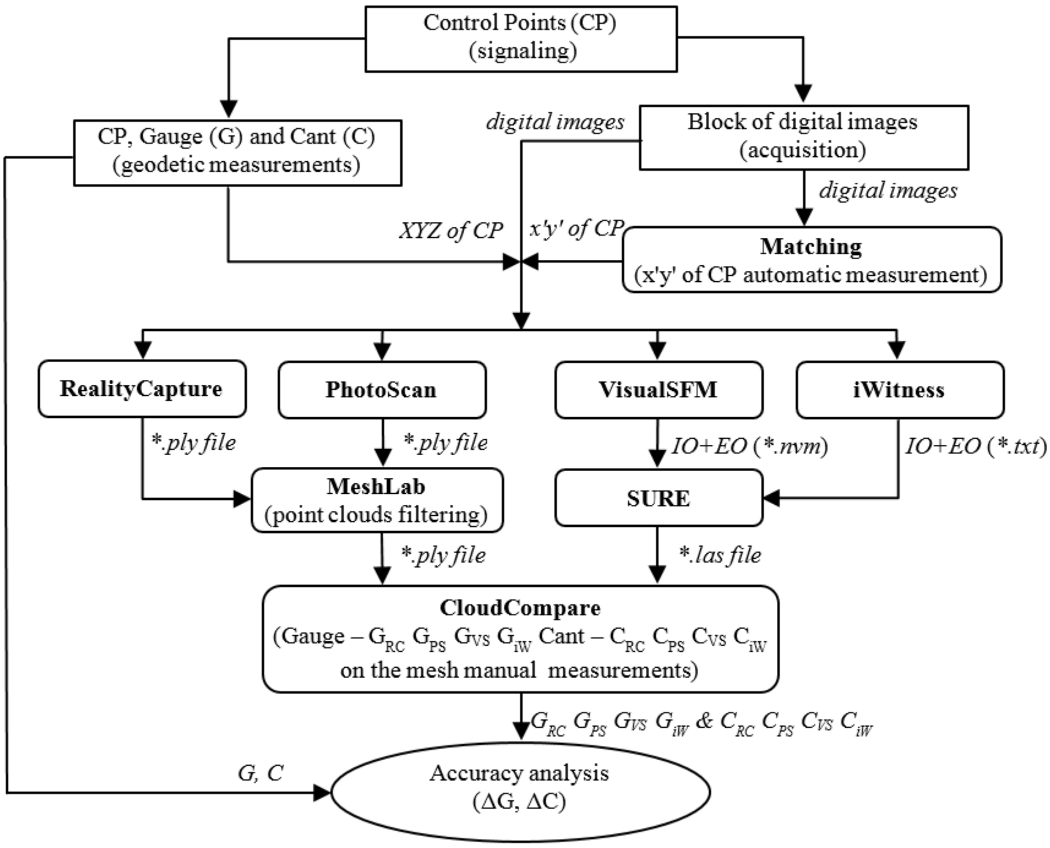

Fig. 3. Photogrammetric measurements and processing workflow
(source: own elaboration)

Point clouds generation using the tested software

Automatic determination of interior orientation elements (IO) for the DSLR Nikon D5100 camera, the elements of the spatial orientation (EO) of photos and generation of the dense point cloud were performed using four applications:

- RealityCapture v. 1.0.2.2256 (commercial license) of Capturing Reality s.r.o (Jancosek, Pajdla 2009; Jancosek *et al.* 2009).
- Agisoft Photoscan v. 1.2.6 (commercial license) – Agisoft LLC (Jaud *et al.* 2016; Niederheiser *et al.* 2016; Remondino *et al.* 2014).
- VisualSFM of Wu C. (educational license) (Wu *et al.* 2011; Wu 2013) + SURE of IfP (educational license) (Haala, Rothermel 2012; Rothermel *et al.* 2012; Wenzel *et al.* 2013).
- iWitness v. 3 of Photometrics (trial license) (Wendt, Fraser 2007) + SURE of IfP (educational license).

All applications are dedicated, first of all, for dense point clouds generation and 3D objects reconstruction basing on the large number of variously oriented digital images. Selection of functions, configuration and modification of data processing options are an interactive and manual mode performed in RealityCapture and Agisoft PhotoScan software. In the case of VisualSFM and iWitness software it is impossible to modify data processing settings. Different functionality of all tested tools required another methodology of the advanced digital processing.

Before image processing was performed using the tested software systems, the structural signalled points were measured using the weighted center method (centroid operator) by means of Matching, the original software (Sawicki, Ostrowski 2005) with the mean subpixel accuracy of the automatic measurement $m_{x'y'}$ = 0.15 pixel.

RealityCapture settings

RealityCapture software is based on the scalable multi-view stereo (MVS) method. Image matching, construction and colourising of a model are required to generate the coloured dense point cloud in the RealityCapture. Image matching was performed using the “Alignment” option. The detector sensitivity was set to “High”, max. features per megapixel was set at 20 thousands, max. features per image was set at 80 thousands, max. feature reprojection error was set at 2.0, images overlap was set to "High" and image downscale factor was set at 1.0. The camera calibration model was selected by defining the number and approximate values of parameters to be determined. The model was generated according to the "Normal" variant with manual parameter settings. During the model generation: in image depth map calculation – image downscale was set at 2.0, the model colourise image downscale was set at 1.0 and the colouring method was set to multi-band.

PhotoScan settings

The Agisoft PhotoScan application uses the stereo semi-global matching (SGM) approach. When the PhotoScan application is used to generate a 3D point cloud, image matching and generation of a colour dense point cloud must be performed. For that purposes the processing accuracy was set as "Highest" with searching for tie points for each possible stereo-pair (option "Pair preselection: disabled"). The key points limit was set at 200 thousands and the tie points limit was 40 thousands. The dense point cloud was generated at "High" settings with the aggressive depth filtering. Texture building was performed with the mapping model "Generic" and "Average" blending mode.

VisualSFM with SURE settings

Generation of a dense point cloud using the VisualSFM and SURE package is performed through image matching and reconstruction of a sparse point cloud with key points and densification of the point cloud. VisualSFM uses the incremental Structure for Motion approach, which is based on the preemptive matching method combined with re-triangulation and full bundle adjustment. The result is NView Match, being the initial data for densification of the point cloud by the use of the multi-view stereo method (MVS) implemented in SURE application. The user cannot affect the maximum number of tie points per megapixel and per image. The dense point cloud was generated with the full resolution, without image scaling.

SURE is a software, which enables the derivation of dense point clouds from a given set of images and the corresponding interior and exterior orientations. This orientation can be derived either automatically (e.g. by Structure from Motion methods) or by using classical image orientation approaches.

iWitnesss with SURE settings

The applied trial version of iWitness software did not offer the embedded modules, which allows for dense point clouds generation. For that purpose the SURE application was utilised, being the module in Agilis version of iWitness software. Works were started from the automatic orientation of a set of photos, using the implemented feature based matching approach. When the spatial image orientation based on automatically detected tie points was applied, and control points coordinates were inputed, the photogrammetric points intersection errors were occurred and absolute orientation of model was not possible. Therefore the data processing sequence was modified. First pixel and object coordinates of control points were entered and then the bundle adjustment was performed. The geometry quality factor amounted to 1.4 in the discussed project. Orientation parameters exported in the file (IO+EO.txt) were then used as initial data for the SURE application. Further works were identical with operations described in previous subsection about VisualSFM+SURE software package.

Point clouds filtering and measurement

The following packages were applied for advanced point clouds processing and measurements:

- MeshLab v. 1.3.3 – Visual Computing Lab of ISTI-CNR (GNU GPL license) (Cignoni *et al.* 2008).
- CloudCompare v. 2.8 – (GNU GPL license) (CloudCompare 2016).

The dense point clouds of the test section of railway tracks generated with the use of RealityCapture and PhotoScan softwares were further processed using MeshLab application. Model filtration consisted of elimination of surrounding areas of the test section. The final section of the railway track point clouds model was limited to the width of the railway sleeper and to the distance between 3 successive sleepers.

The track gauge (G) and cant (C) values were determined for the 3 cross sections of the test railway track section using CloudCompare application. Within the area, where control points were located, for the section d = 1.5 m a tracing line was marked along the rail and cross sections were created with the interval Δd = 0.75 m. The interest areas of the cross sections were the cant points, located in the centre of the rail heads and the gauge points defined at the side of the rail heads, 15 mm below the cant point. Results of measurements of gauge and cant are presented in Figure 4. First, cant points and then gauge points were determined. Differences of elevation between the cant points were the cant value and the gauge value was analytically calculated on the basis of measured coordinate values. The measured gauge and cant values were compared with the results of direct geodetic measurements.

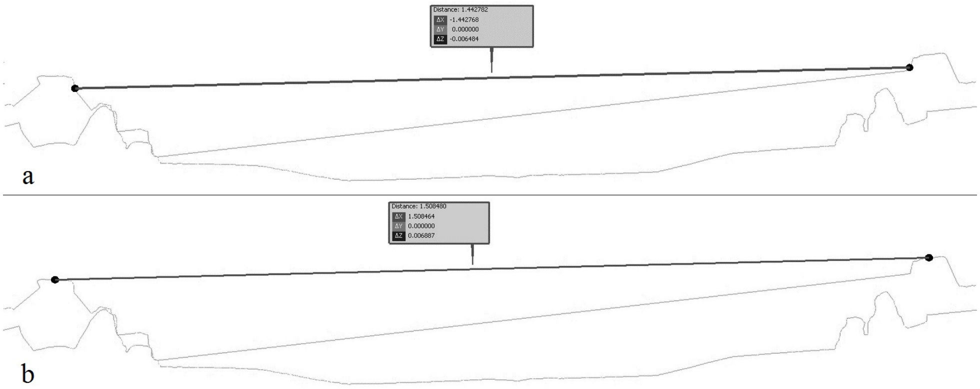

Fig. 4. Geometric parameters (track gauge and cant) determination in CloudCompare application based on point clouds generated in RealityCapture software – example one cross section: gauge (a), cant (b) (source: own elaboration)

Results

All tested applications were used for processing on the workstation with the processor Intel® Core™ i7-950 (8M Cache, 3.06 GHz), 24 GB RAM DDR3-1333MHz memory, NVIDIA® Quadro® 4000 graphic card and SATA3 7200 rpm disk. Table 1 presents parameters and results of processing of generated point clouds. Calculated RMS values are related to deviations on control points of the 3D model.

Table 1. Parameters and results of processing (source: own elaboration)

Processing parameters & results	RealityCapture	PhotoScan	VisualSFM+SURE	iWitness+SURE
Processing time	27 min. 32 sec.	47 min. 13 sec.	1137 min. 41sec.	1131min. 2 sec.
Point cloud coverage area	63.21 sq m	25.4	78.05	54.78
No. of used tie points	209 319	383 190	–	–
No. of cloud points	4 067 051	4 012 253	66 227 273	5 711 648
Point density per sq m	64 342	157 963	848 524	104 265
No. of cloud points in interest area	2 158 234	1 236 918	35 407 544	3 208 941
Interest area coverage	5.29 sq m	5.06 sq m	5.31 sq m	6.06
Interest area point density per sq m	407 984	244 450	6 668 087	529 039
StDev $s_{x'y'}$ on CP	0.67 pix	0.42 pix	–	1.7 pix
RMSΔ_{XY} Dev on CP	0.323 mm	0.428 mm	–	0.608 mm
RMSΔ_{Z} Dev on CP	0.268 mm	0.270 mm	–	0.500 mm
RMSΔ_{XYZ} Dev on CP	0.306 mm	0.383 mm	–	0.574 mm

Visualisations of point clouds models generated with the use of RealityCapture, PhotoScan, VisualSFM+SURE and iWitness+SURE applications are presented in Figure 5. The software packages with SURE applications generated the most dense point clouds with the "Full resolution" option setting, nevertheless by the extremely long processing time. The RealityCapture and PhotoScan applications generated point clouds of the significantly lower density, as a result of using the option "Image downscale factor equal 2". Within the interest area of the 3D surface reconstruction obtained using RealityCapture application was characterised by the higher quality, since the point cloud density was doubled comparing to the PhotoScan results. The 3D model orientation accuracy is similar for both applications and it is almost doubled comparing to iWitness application. It was impossible to directly assess the model matching accuracy on control points when VisualSFM application was applied.

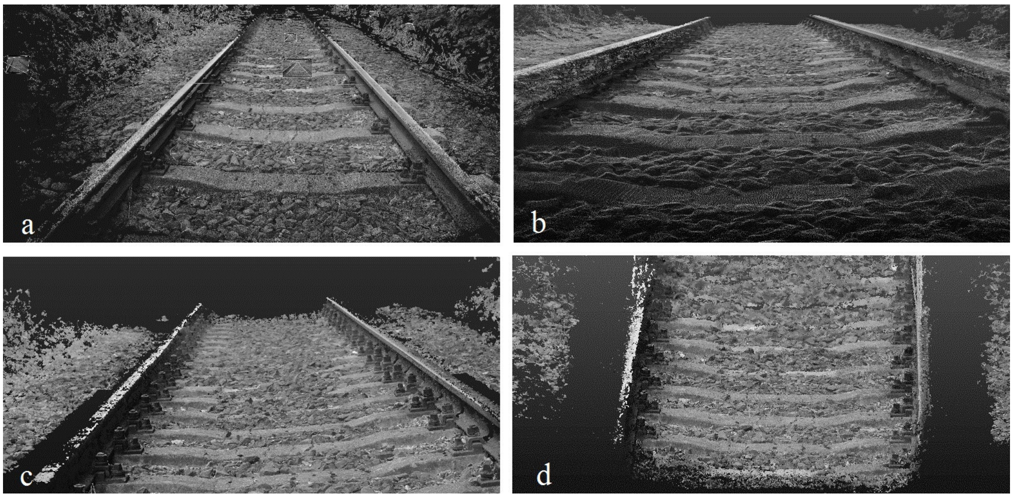

Fig. 5. Visualization of point clouds generated using tested applicatuions: RealityCapture (a), PhotoScan (b), VisualSFM+SURE (c) and iWitness+SURE (d) (source: own elaboration)

Table 2. Track gauge (G) measurements results in CloudCompare application (source: own elaboration)

No. of cross section	Gauge measurement (mm)					Measurements differences (mm)			
	Geodetic (G)	Reality Capture (G_{RC})	PhotoScan (G_{PS})	VisualSFM +SURE (G_{VS})	iWitness +SURE (G_{iWS})	ΔG_{RC} = = G-G_{RC}	ΔG_{PS} = = G-G_{PS}	ΔG_{VS} = = G-G_{VS}	ΔG_{iWS} = = G-G_{iWS}
1	1443.0	1442.8	1443.4	1443.0	1499.2	0.2	–0.4	0.0	–56.2
2	1442.8	1443.0	1443.0	1443.0	1503.3	–0.2	–0.2	–0.2	–60.5
3	1442.4	1443.0	1443.0	1443.0	1480.9	–0.6	–0.6	–0.6	–38.5
				RMSΔG $_{RC, PS, VS, iWS}$		0.38	0.43	0.37	52.60

Table 3. Cant (C) measurements results in CloudCompare application (source: own elaboration)

No. of cross section	Cant measurement (mm)					Measurements differences (mm)			
	Geodetic (C)	Reality Capture (C_{RC})	PhotoScan (C_{PS})	VisualSFM +SURE (C_{VS})	iWitness +SURE (C_{iWS})	ΔC_{RC} = = C-C_{RC}	ΔC_{PS} = = C-C_{PS}	ΔC_{VS} = = C-C_{VS}	ΔC_{iWS} = = C-C_{iWS}
1	7.0	6.9	6.5	7.1	8.1	0.1	0.5	–0.1	–1.1
2	7.5	7.1	7.9	7.0	7.9	0.4	–0.4	0.5	–0.4
3	8.5	8.3	8.8	8.5	9.2	0.2	–0.3	0.0	–0.7
				RMSΔC $_{RC, PS, VS, iWS}$		0.26	0.41	0.29	0.79

Table 2 presents the track gauge data, whereas Table 3 contains cant values, measured directly in the field using geodetic equipment and determined by measurements of 3D models using CloudCompare application. The following track gauge and cant difference values were obtained for defined 3 cross sections (Table 2, Table 3) using four tested software applications: $RMS\Delta G_{RC}$ = 0.38 mm, $RMS\Delta G_{PS}$ = 0.43 mm, $RMS\Delta G_{VS}$ = 0.37 mm, $RMS\Delta G_{iWS}$ = 52.60 mm and $RMS\Delta C_{RC}$ = 0.26 mm, $RMS\Delta C_{PS}$ = 0.41 mm, $RMS\Delta C_{VS}$ = 0.29 mm, $RMS\Delta C_{iWS}$ = 0.79 mm. Including the measurement errors of used control points the final measurement error (m_{XYZ}) of geometric parameters is approx. 0.2 mm biger. Calculations proved that RealityCapture application allows achieving repeatable results of measurements of geometric parameters of a railway track.

Conclusions

The image based dense point cloud generated as big data allows accurate and complete reconstruction of a 3D object. The required configuration of multi images is necessary to generate dense point clouds and compensates disadvantageous geometric and radiometric conditions, which occur in the functional model of a some applications in digital close range photogrammetry. It was stated basing on performed research works that for three software applications: RealityCapture, PhotoScan, VisualSFM+SURE, tested within the project, the RMS difference between geodetic and photogrammetric measurements in horizontal and vertical planes was RMSΔ < 0.5 mm.

Comparison of the processing results and measurements proved the higher usefulness of RealityCapture application, which faster generated 3D robust models of the higher quality and precision. Besides, it is a more user friendly package.

The tests proved that, the image based dense point cloud allow, in the case of disadvantageous conditions of photogrammetric digital data processing, to determine the geometric parameters of a close range elongated object (the section of a railway track) with the high accuracy (m_{XYZ} < 1 mm).

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