Accuracy analysis of 3D model obtained by photogrammetric method on the example of historic room from Wisłoujście Fortress

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Abstract. The article presents a comparison of obtained models of a test object. Close range photogrammetry was used to obtain 3D models. As test object was used one of the rooms located in Wisłoujście Fortress in Gdańsk, Poland. Different models were obtained by using different distribution and number of reference points. Article contains analysis of differences between coordinates of control points obtained from total station measurements and estimated from different 3D models.

1 Introduction

Obtaining spatial information (in the form of point clouds) for the purpose of geometric archiving or spatial analysis of measured objects is a method increasingly used in engineering practice [1, 2, 3]. In most cases, laser scanners are used to obtain a point cloud [4]. They are measuring distance and angles and in that way, a point cloud is created. However, these types of instruments and software used by them are very expensive. For this reason, the method of laser scanning in some cases does not apply. As an alternative method of acquiring spatial data, in form of point cloud, photogrammetric method is increasingly used. Software development and more advanced cameras enable to obtain satisfactory data in a much simpler way and at more competitive prices [1, 5]. This article presents accuracy analysis of 3D model obtained by photogrammetric method using non-metric digital cameras. The analysis was made based on coordinates of arranged photopoints grid within the measured room. The grid consisted of 134 photopoints was measured by total station in local coordinate system. Leica TPS 1200+ total station was used for the measurements.

2 Development of a 3D model

A room located within the area of Wisłoujście Fortress in Gdańsk was used as test field. The room was characterized by a complex geometry. It was built on plan of a ring segment, ceiling is a cross vault. Corridor separated by an additional wall is also a part of the room. The room is equipped with a brock kitchen hood and a chimney hole that further complicates its geometry (Fig. 1 and Fig. 2).

Fig. 1. Cross section of the room.

Fig. 2. "Outside" view of room's model.

The room's spatial model was made using the non-metric photogrammetry method. For this purpose, two cameras with fixed focus lenses were used: Canon EOS 5D (full frame 12 Mpix sensor) with Sigma 50mm f / 1.4 lens and

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Canon EOS 350D (with APS-C 8 Mpix sensor) with Canon 28mm f / 2.8 lens. In total, several hundred photographs of the room were taken, which at further study stage were given a geometrical analysis. The spatial model was generated in Agisoft Photoscan Pro software.

2.1. Points position combinations accepted for development

There are two points types in study: control points used to determine accuracy of obtained model and reference points to fit model into local coordinate system.

Different combinations of reference points placements on walls, floor and ceiling were used for analysis. The combinations used, their subsequent determinations and control points number are shown in Table 1. Prim (') designation means setting where used points created another possible diagonal. As reference was used situation when all measured points were used in model development (the case marked "Max").

Example of point positions on different walls was shown at Fig. 3

Table 1. List of accepted combinations of points distribution and control points number.

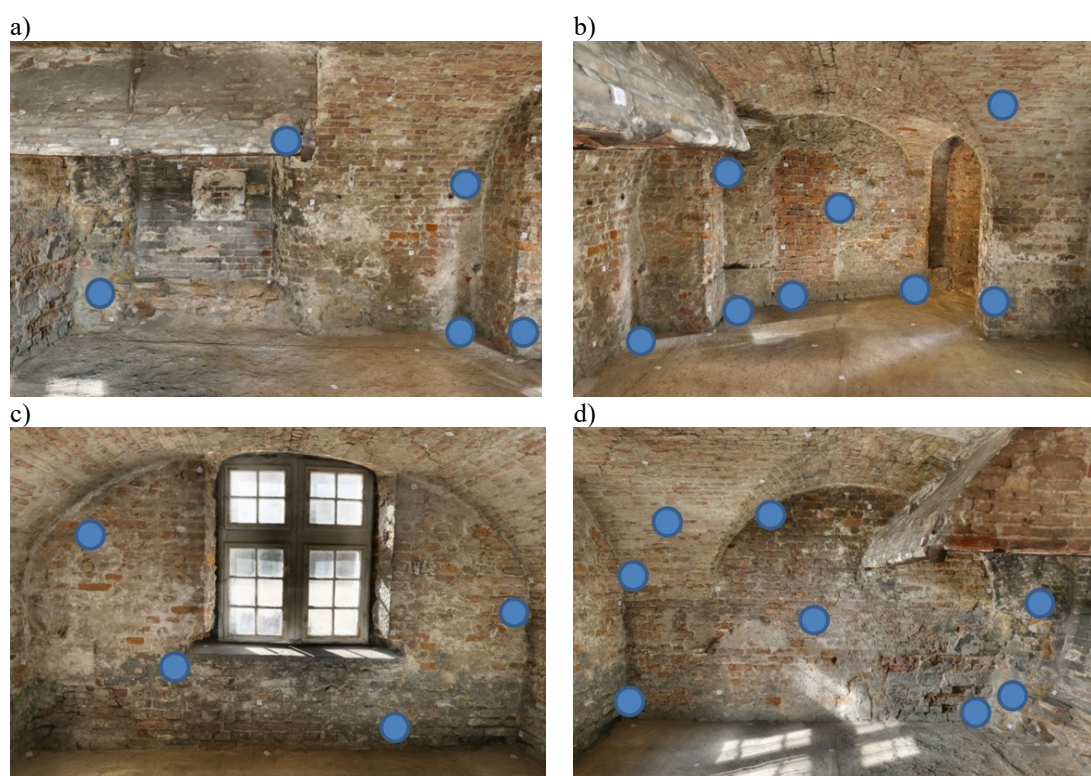| Determination of the combinations	Points position, their number and symbol							Number of control points
	Wall				floor	ceiling	hood	
	N	S	E	W	D	G	Ok	
1	1	1	1	1	1	0	0	93
1NSEWD_Ok	1	1	1	1	1	0	1	93
1NSEWDG	1	1	1	1	1	1	0	93
1NSEWDG_Ok	1	1	1	1	1	1	1	92
2N'S'E'W'D'G'	2	2	2	2	2	2	0	89
2N'S'E'W'D'G'_Ok	2	2	2	2	2	2	1	88
2NESWDG	2	2	2	2	2	2	0	90
2NESWDG_Ok	2	2	2	2	2	2	1	89
4D	0	0	0	0	4	0	0	94
4E	0	0	4	0	0	0	0	96
4E_Ok	0	0	4	0	0	0	1	96
4N	4	0	0	0	0	0	0	94
4N_Ok	4	0	0	0	0	0	1	93
4S	0	4	0	0	0	0	0	95
4S_Ok	0	4	0	0	0	0	1	94
4W	0	0	0	4	0	0	0	94
4W_Ok	0	0	0	4	0	0	1	93

Fig. 3. Example of reference points position: a) north wall, b) east wall, c) south wall, d) west wall.

2.2. Image processing

In the first stage, all measured points on pictures were marked. In addition, measured points coordinates were imported to project. In order to check correctness of point assignment, preliminary merging of photos was performed and it was checked whether any of points generated a large matching error (in this case, level of 1 cm was assumed). In this way, data for the "Max" combination have been prepared. The remaining combinations were created by removing those points that were not supposed to be reference points.

Projects prepared in this way, consisting of photographs with reference points marked on them, have been further processed. Firstly, photos were aligned with "accuracy" parameter set to "high" and with enable pair preselection. Next step was camera's parameters optimization. Next stage, considered in this study, was automatic recognition of points in the pictures, which weren't reference points (control points were created). Deliberately, no points were added manually to check how good results can be obtained from a study done in a maximum automated manner. In this case, used software was able to recognize 96 out of 134 points (71 % of distributed tags). The last step was to export estimated coordinates of control points. In data export, a mathematical coordinate system was used.

3 Measurement results analysis

Based on points coordinates obtained from total station measurement and coordinates estimated from model, differences between coordinates were calculated using the equations:

$$\Delta X = x_{meas} - x_{est} \tag{1}$$

$$\Delta Y = y_{meas} - y_{est} \tag{2}$$

$$\Delta Z = y_{meas} - y_{est} \tag{3}$$

where "meas" index means coordinate from total station measurement and "est" index means coordinate obtained from model.

Additionally, spatial coordinates differences R were calculated using equation:

$$R = (\Delta X^2 + \Delta Y^2 + \Delta Z^2)^{0,5} \tag{4}$$

Calculated differences were used to calculate the first, second (median) and third quartiles. Quartiles were used to compare results due to lack of distribution normality of obtained differences ΔX, ΔY, ΔZ, R. Comparison of obtained quartile values for each combination are shown on Fig. 4 to Fig. 11.
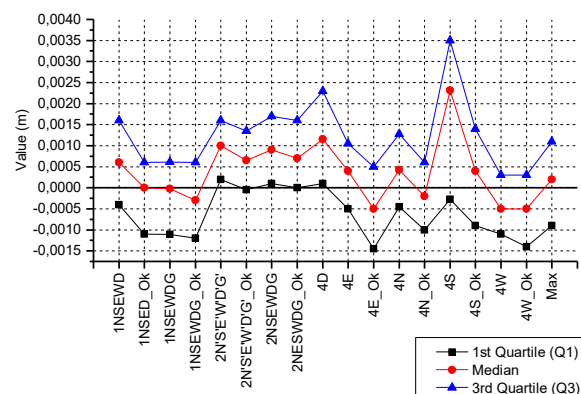

Fig. 4. Quartile values list of coordinate differences for X axis sorted by a reference point combination.
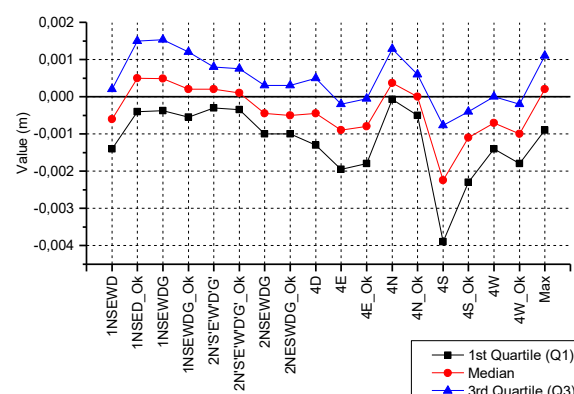

Fig. 5. Quartile values list of coordinate differences for Y axis sorted by a reference point combination.
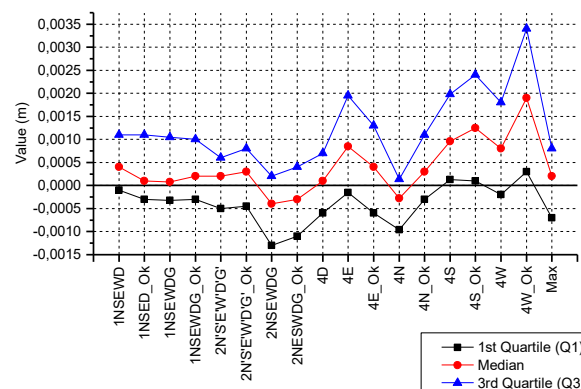

Fig. 6. Quartile values list of coordinate differences for Z axis sorted by a reference point combination.
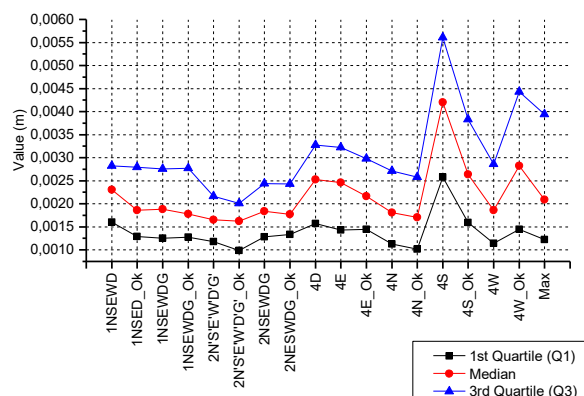
Fig. 7. Quartile values list of "spatial differences" R sorted by a reference point combination.

Fig. 8. Quartile values list of coordinate differences for X axis sorted by increasing median value.

Fig. 9. Quartile values list of coordinate differences for Y axis sorted by increasing median value.

Fig. 10. Quartile values list of coordinate differences for Z axis sorted by increasing median value.

Instrument used for measurements had point position accuracy of an order of 2 mm. For this analysis, it must be remembered that differences less than 2 mm are irrelevant. Analysing data presented on Fig. 4 to Fig. 7, it can be noticed that in most cases, addition of point located on hood to calculations improves correspondence of measured and estimated coordinates of control points. In addition, in the case of a combination related to points located on walls and floors diagonals, differences are practically the same. From considered combinations, the biggest variance between measured estimated values can be seen for combination "4S". In this combination, one of used reference point was located on windowsill and was located horizontally. A significant incidence angle of laser beam caused that point position was measured with a larger error. An error in determining coordinates of this reference point caused a worse model adjustment to coordinate system than when using reference points measured at optimal angle. In case of combinations in which reference points were located only on room's walls or floor, comparable coordinate differences were obtained. In the case of "Max" combination, all reference points were control points at the same time. In this case, it is possible to check used software's ability to reproduce object's geometry. It can be seen that coordinates differences are not greater than coordinates accuracy calculated based on total station measurements. The median for "spatial differences" corresponds to total station's distance measurement accuracy (2 mm). However, the third quartile (75 % of results is less than quartile value) reaches 4 mm, which wasn't observed for other considered combinations. It can be caused by using a larger number of points, some of which were measured at an unfavourable incidence angle of laser beam emitted by total station's rangefinder.

Fig. 8 to Fig. 11 presents charts with sorted median values for various combinations of considered reference points.
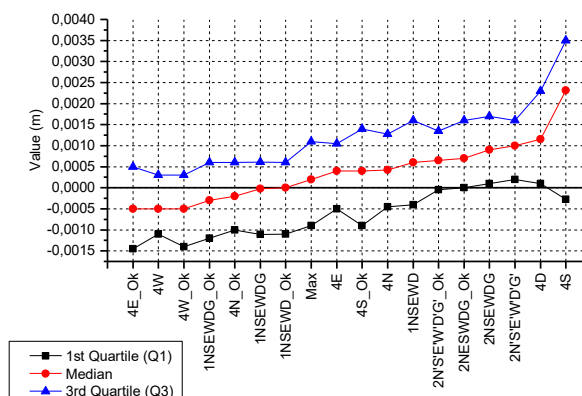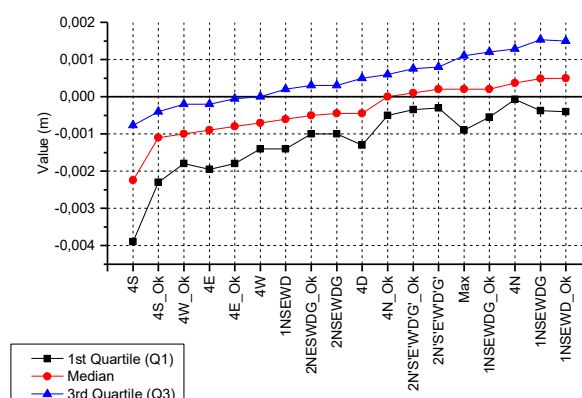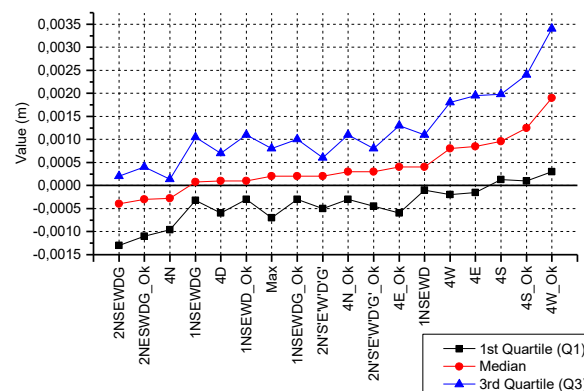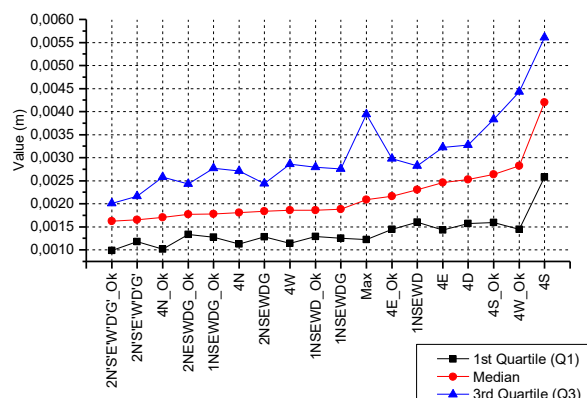
Fig. 11. Quartile values list of "spatial differences" R sorted by increasing median value.

By analyzing the sorted median values for the differences of individual coordinates, it can be noticed that the combinations with the highest number of points gave results comparable to "Max" combination. The worst results were obtained when points were placed only on one wall, but also when one point was placed on all surfaces simultaneously (combination of 1NSEWD). It follows that it is best to measure points that will be in places where object's geometry changes. In this way, time of field measurements can be optimized, because measurements of reference points are one of the more time-consuming processes performed in the field.

4 Summary

In process of making a model based on images, it is important to skilfully arrange markers and take pictures of object. Properly placed and photographed markers enable quick and accurate execution of object's digital model. Reference points should be chosen wisely because their measurement can be one of the longer stages during field work. On the one hand, reducing the number of reference points results in faster measurements. On the other hand, this requires increased attention while measurements so that all measurements will give correct results.

It is important to properly arrange the reference points on measured object. They should be placed in places where a character of object's geometry changes, eg near surface bends. In general, they should "surround" object which will be modelled. In this way, number of points needed to measure will be minimized and obtained results will be in line with expectations.

References

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