Comparison of point clouds captured with terrestrial laser scanners with different technical characteristic

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Abstract. Terrestrial Laser Scanners come with different technical parameters like the wavelength (laser colour), range or even the distance measuring method. Within this work the surface of a large-scale concrete - Rožnów Dam -structure was captured by three different Terrestrial Laser Scanners with different technical parameters - Leica C10, Riegl VZ-400 and the Z+F Imager 5010. The captured three dimensional point clouds were further evaluated by analysing the parameters of a fitted plane in each case that has been derived with the help of a least squares adjustment. This paper describes different analysis of registered point clouds. Presented results indicate significant differences between representations of scanned surface, measured in the same weather conditions, using three different scanner models. Analysis revealed differences in “grain” and texture of obtained visualization, as well as registered data completeness. These differences might play a significant role during conducting analysis of an engineering object changes and deformations based on point clouds registered in different time periods.

Keywords: Terrestrial Laser Scanning, fitting plane, least square method.

Introduction

The use of Terrestrial Laser Scanning (TLS) has increased in popularity over the last few decades in surveying, geodesy and other fields. The instruments that are employed for TLS belong to a relatively new technology and they often come with different technical parameters like the wavelength (laser colour), range or even the distance measuring method. Usually the selection of the instrument to be used in a project is based on its availability and cost. However an analysis of the object to be captured is essential and the required measurement accuracy should be always taken into consideration for a realistic and optimal choice of the instrument.

Scanners can be divided in two groups, phase-based scanners and pulse-based scanners. The range of observations is determined by the scanning technology. Phase based scanners are dedicated for closer distances (currently up to 200 m), whereas pulse based scanners allow for measuring objects situated much further away from the observation point (up to few kilometres). Depending on the measuring distances scanners are categorised into: short, medium and long range. This entail second characteristic: measurement accuracy. Accuracy values depend of the distance measuring mode (phase based or pulse based) and instrument type and model and vary between couple of millimetres and several centimetres [1].

Definition of laser scanning accuracy is difficult since it is influenced by factors such as:

- weather conditions,
- accuracy of determination of tie-in points for different scans,
- accuracy of reference to the external coordinate system,
- laser beam incidence angle,
- type and colour of reflecting surface,
- wavelength,
- object geometry, which can cause an “multi-way” effect,
- surrounding light,
- instrument errors.

Final results of laser scanning are not single points coordinates, but geometrical model inscribed into obtained point clouds.

Difficult terrain conditions accompanying dam sites determine selection of specialist instruments as well as appropriate geodesic measuring techniques. Proximity of water environment affect local microclimate conditions, which not always conduce to observations of expected accuracy. Enormous scale and specific terrain conditions make water dams ideal test objects for conducting research utilizing terrestrial laser scanning.

Research

Within this work the surface of a large-scale concrete structure – Rožnów Dam (Fig. 1) was captured by three individual Terrestrial Laser Scanners with different technical parameters, namely the Leica C10, Riegl VZ-400 and the Z+F Imager 5010 (Table 1). Within he conducted tests 6 non-overflow dam sections each 15 m wide and 44 m high were surveyed. All measurements were performed on the
same position during data acquisition and under the same atmospheric conditions.

Figure 2 is presented results of the scanning selected three sections scans. Point clouds of the object. Cloud points has been colorized based on the registered value of the intensity of the laser beam reflection. It is noticeable, that for each of the scanners used for tests Intensity of Reflection was registered in ranges varying in regards to interval value as well as number of values registered within. Differences in hue intensity can be noticed on Image of Intensity visualisations (Fig. 2). Image acquired using Riegl VZ-400 scanner show few clearly separated, indicated in orange colour areas which are not so articulated on images from other two scanners. At this stage it can be stated that depending of instrument used not only the geometrical model of surveyed object can be obtained, but also additional information can be acquired.

Table 1. Comparison of used scanners

<table>
<thead>
<tr>
<th></th>
<th>Leica ScanStation C10</th>
<th>Riegl VZ-400</th>
<th>Z+F Imager 5010</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type of laser</td>
<td>impulse</td>
<td>impulse</td>
<td>phase</td>
</tr>
<tr>
<td>Colour</td>
<td>green</td>
<td>near-infrared</td>
<td>near-infrared</td>
</tr>
<tr>
<td>Wavelength</td>
<td>532 nm</td>
<td>1550 nm</td>
<td>no data</td>
</tr>
<tr>
<td>Scan range Minimum</td>
<td>0,1-300</td>
<td>0-600</td>
<td>0,3-187,3</td>
</tr>
<tr>
<td>Maximum [m]</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Accuracy of single</td>
<td>4/50 0,0033°</td>
<td>5/100 0,0005°</td>
<td>0,3/10 0,007°</td>
</tr>
<tr>
<td>measurement of:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>distance [mm/m]</td>
<td>angle</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Purpose (according</td>
<td>engineering measurement, surveying, installation, architecture, monuments,</td>
<td>inventory of buildings, archeology, urban modelling, measurements tunnels, civil engineering</td>
<td>topographic al surveys and mining, civil engineering, archeology, forestry, forensic examination</td>
</tr>
<tr>
<td>to manufacturer</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Scanning range</td>
<td>0,1-300</td>
<td>0-600</td>
<td>0,3-190</td>
</tr>
<tr>
<td>minimum – maximum [m]</td>
<td></td>
<td></td>
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</tr>
</tbody>
</table>

The captured three dimensional point clouds were further evaluated by analyzing the parameters of a fitted plane in each case that has been derived with the help of a least squares adjustment. The estimated plane parameters

Figure 2. The results of surface scanning – Image of Intensity of point clouds – scanner: Leica Scan Station C10, a) view of front, b) side view of the point clouds; Riegl VZ-400 c) view of front, d) side view of the point clouds; Z+F Imager 5010, e) view of front, f) side view of the point clouds

Figure 3. Illustrations of the results of fitting the surface by least square method into point clouds measured by: a) Leica Scan Station C10 b) Riegl VZ-400 c) Z+F Imager 5010
Comparison of point clouds captured with terrestrial laser scanners with different technical characteristics accompanied with their standard deviations, as well as the minimum and maximum deviation of every point cloud to the fitted plane can serve quality measures for assessing the applied procedure (TLS). Therefore rules for the optimal selection of the instrument to be used can be formulated depending on the requested accuracy of the model. The results of our analysis presented Figure 3 and Table 2. Table shows selected parameters of estimated plane (A, B) and their average standard deviations s0. Accuracy of fitting planes is comparable with the value +/- 5 cm. The weakest fitting was carried out for scanner Z+F Imager 5010.

The results of automatic plane detection in 3D point clouds may be one of criteria for comparisons of scans. One of the possibilities is to use algorithms of detection, for example Ransac algorithm [2]. The next criteria may be results of comparison of registered intensity reflection of the laser beams. The possibilities to utilize values of the intensity for assessment of a surface of a concrete hydrotechnical structure was presented in [3].

Three point clouds acquired with three terrestrial laser scanners were subject of additional analysis, in regard to “thickness” and texture of obtained surface image. For this purpose three points defining a plane (Fig. 4) described with formula $Ax+By+Cz+D=0$ were selected, where: $A=66,03520; B=392,89050; C=273,81465; D=1108,08893$.

With regard to the character of observed wall these points were located on the lower part of the scans, on the sloping part of the downstream face of the dam. Points defining the plane were chosen so, that for each analyzed point clouds they are located in closest average distance from three registered points in a cloud.

In the next step, for each of the point clouds registered with three mentioned above methods a visualization of distance from the given plane was created (fig. 5, fig. 6). Figures indicate points enclosed within distance from the plane boundary ranges: ±1 cm (Fig. 5), ±10 cm (Fig. 6). Rainbowscale adopted for images is representing relative accuracy of fitting planes.

Table 2. Calculated values of the fitting planes and surfaces in the registered point clouds

<table>
<thead>
<tr>
<th></th>
<th>Leica ScanStation C10</th>
<th>Riegl VZ-400</th>
<th>Z+F Imager 5010</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plane parameter A</td>
<td>0.20798581</td>
<td>-0.23940985</td>
<td>1.128409767</td>
</tr>
<tr>
<td>Plane parameter B</td>
<td>1.43702528</td>
<td>-1.43411206</td>
<td>0.927022129</td>
</tr>
<tr>
<td>s0</td>
<td>0.0501 m</td>
<td>0.0504 m</td>
<td>0.0592 m</td>
</tr>
</tbody>
</table>

Figure 4. Selected points (white colour) defining the plane used for comparison analysis

Figure 5. Graphical visualisation of point clouds located in range $a=1$ cm from defined plane, a) Leica Scan Station C10, b) Riegl VZ-400 c) Z+F Imager 5010 d) Rainbowscale
distance ranges \((-a,a)\)=\((-1, 1)\) and \((-a,a)\)=\((-10,10)\) cm, with colour change every at 1/30\(^{th}\) of range. Images show difference in representing details at estimated measurement accuracy exceeding 0.5-2 cm. Presented visualizations were realized using dedicated software created by Janina Zaczek-Peplinska.

Also the completeness of data acquired at various distances from instrument was analyzed. Maximum scanning range for specific instruments as specified by the manufacturers is shown in Table 1. For surface of cleaned concrete in the middle and towards the edges of the dam comparable quality of data was acquired for distances 20 m +/- 5 cm and beam angles 0 and 45 degrees. For wider angles and distances exceeding 90 m (half of nominal Z+F Imager 5010 range) number and quality of registered data is significantly different. On the basis of the measurements, the number of points returned to the scanner and intensity of the reflected beam were analyzed. Best quality of imaging was registered using Leica ScanStation C10, whilst the least using Z+F Imager 5010 scanner. Obtained results are related to two technical parameters of those instruments:

- laser colour – near infrared radiation is absorbed by damp, covered with vegetation and soiled surfaces to a larger extent than radiation in green range, and there is no possibility to obtain 100% of clean concrete on the surface of hydrotechnical object without interference with its surface structure.

- range – experiments and research for example [4] indicate lower completeness of data for distances greater than half of nominal range and angles greater than 45 degrees.

Conclusions

The use of Terrestrial Laser Scanning (TLS) has increased in popularity over the last few decades in surveying, geodesy and other fields. There are more frequent attempts of terrestrial laser scanning application for an engineering objects technical control, especially for evaluation of periodical changes and deformations related to various sources, such as weather conditions (wind speed, insolation, humid-
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ity), or structure loads (related to day-to-day operation e.g. changes of water level in a dam reservoir, increase of vehicular traffic on the bridge, building additional floors to the building, modernization of elevations, construction sites utilizing deep excavations in the near proximity of the object). Atmospheric conditions during measurements, object size, as well as expected magnitudes and disposition of changes should be taken into consideration while selecting an instrument for the task. Article shows, that in result of measurements of the same surface, using different instruments, three different surface models, different texture representations, and different images of intensity were obtained. It should highlighted, that observed variations are not significant in case of architectural survey, but play a major role in large engineering objects periodic monitoring. In cases, where small changes, indicating lack of structural elements stability are expected, comparison of point clouds obtained using different instruments is incorrect. Indicated changes might be a result of different measuring technologies, not the actual changes of the object.

Presented in this paper work is an introduction to planned research, but already at this stage further conclusions can be drawn based on its results. Research proved, that technical parameters of used instrument have a great influence not only in respect to geometry, but also, quality and completeness of data. Moreover the analyzes carried out indicate that the variation of the geometry of the mapped surface depends on the texture, colour and slope of measured surface and distance from the object to position of the instrument. Summarizing presented works we would like to emphasize significance of right instrument selection depending on type of performed task and type of measured object.

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Bibliography

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