STOP & GO SCANNING FOR HIGHWAYS – 3D CALIBRATION METHOD FOR A MOBILE LASER SCANNING SYSTEM

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Abstract

A 3D calibration method was developed for a mobile laser scanning system developed in Finland. The measurement accuracy was validated using a robotic total station for reference measurements, with comparison of reference points with the triangulated surface measured by the laser scanning system. The calibration results are presented and analyzed. Propagation of random and systematic errors is analyzed mathematically. The adequacy of the accuracy is discussed while comparing the results to the tolerance requirements set by the owner, the Finnish Road Administration. The use of the laser scanning system in a design-build-maintenance-operate project of a motor way in Finland is briefly illustrated.

KEYWORDS: Stop & Go Laser scanning, Mobile, 3D calibration, measurement accuracy

1 INTRODUCTION

All required highway measurements should be performed with sufficient accuracy, adequate reliability, and acceptable economics relative to the application area (Heikkilä 1996, Mikhail & Ackermann 1976, Cooper 1987, Hiremagalur, Yen, Lasky & Ravani 2009). Generally:

(1) Accuracy of measurement can be defined as the capability to produce errorless results.
(2) Reliability of measurement means the capability to maintain accuracy during measurements.
(3) Economy of measurement can be defined as the proportion of the economic advantages produced by the measurement relative to the measurement costs.

Ideally, the accuracy requirement presupposes that systematic errors of measurements can be well–corrected or controlled so that the adequate accuracy of the final results can be obtained.

Also the magnitude of random errors must be sufficiently decreased to achieve sufficient measurement certainty. The reliability requirement renders necessary the different gross, systematic, and random errors occurring in practical measurements to be detected and controlled among the observations. One should be able to eliminate gross errors as well as correct systematic errors. Furthermore, one should always be able to estimate random errors in order to enable the evaluation of uncertainty and thus the usefulness of the results. The economic profitability of measurements presupposes that the costs of the measurements are lower than the financial advantages obtained (Heikkilä 1996).

A surveying company, Mitta Oy, has developed a new Stop and Go Scanning mobile laser scanning system, which has been used for 3D geometric measurements of road surfaces in Finland. The demand for the accuracy of measurement has been set to ±15 mm (relative accuracy demand in *z* direction) by the owner, the Finnish Road Administration (FRA). This prompted research experiments to determinate the accuracy of measurements by the technique in question, along with an evaluation of whether the accuracy is sufficient relative to the demanded tolerance.

Fig. 1. Stop and Go Scanning laser scanning system developed by Mitta Oy.

Stop & Go Scanning is a specialized application of a moving laser scanner: in Stop & Go, measurement of point clouds takes places when the vehicle is stationary. The method is not based on any GNSS or inertia-based system. Four reflectors are been installed on the vehicle, and the positions of reflectors in the project's 3D coordinate system are measured with total station when the vehicle is stationary and performing laser scanning (Jussila 2009). This provides sufficient information to determine the vehicle's 3D pose (position and orientation).

The aim of this research was to determine the accuracy of measurement of the Stop and Go mobile laser scanning system when measuring asphalt surfaces of typical roads in Finland. The second aim was to check whether accuracy is sufficient relative to tolerance. The Stop and Go method may be appropriate for highway application areas where accuracy requirements are most stringent, e.g. pavement elevation surveys. Measurement economy will be investigated in future research.

Fig. 2. A 3D point cloud measured using Stop & Go scanning for a Finland highway.

2 3D CALIBRATION METHOD FOR THE SYSTEM

2.1 Calibration Method

The calibration method was developed and performed in collaboration with Mitta Oy in Nuottasaari, Finland, 2009 (Jussila, 2009). Two professional surveyors of Mitta Oy executed the measurements. The University of Oulu planned, followed and documented the experiments.

Fig. 3. The Stop & Go mobile laser scanning system developed by Mitta Oy.

Fig. 4. The installation of the laser scanner and active targets (prism above the laser scanner is one of four active targets).

A laser scanner and four active targets (prisms) were installed on the system frame (Fig. 4). The frame was found to sufficiently steady and rigid. The system was first calibrated by measuring the prism targets. The laser scanner was controlled remotely by a laptop (Panasonic Toughbook) via TCP/IP using a WLAN connection (Fig. 5). The point clouds were saved into the laptop storage.

Fig. 5. The laptop runs the user interface & communicates wirelessly with the laser scanner.

In the initial calibration phase, four targets were set around the vehicle (see Fig. 6). The measurement station of the total station used was 30 meters from the vehicle. The total station was oriented first, then the targets around the vehicle as well as the prisms in the vehicle were measured by the total station.

Fig. 6. The orientation of the targets and the total station.

Several additional targets were glued onto four different light columns for references points. These points were measured by the total station. After the calibration of the system, the vehicle was driven to the starting position of the measurement (a painted line on the asphalt). The measurement stations were marked by paint at 20 m intervals.

Next, the measurement by the laser scanner was started. At the same time the four prisms of the vehicle were measured by the total station. After these measurements, the vehicle was driven 20 m ahead to the next measurement station. The same measurement process was again repeated as previous one. After measuring from all of the measurement stations, the process was repeated using 30 m intervals. The process is not sensitive to stopping accuracy at the reference stations.

Fig. 7. The reference measurement of the prisms by the total station was guided remotely by a handheld computer.

2.2 Reference measurements

The reference measurements were performed by a different total station later during the same week (Fig. 7). The total station was oriented using the same reference points in the measurement area. Reference points were measured at 5 m intervals and along 3 different lines separated by 5 m (total 10 m width), over a length of 200 m. Thus the points created a 200x10 m^2 grid.

2.3 Comparison of the measurement results

The raw point clouds were first processed using the Z+F LaserControl software. The point clouds were filtered (cleaned) by the Trimble RealWorks software and then reduced to a 20 mm point grid. The calculations were made using 3D WIN software, with which the clouds were reduced to 100 mm grid size. The *xy* coordinates for one point from each 100 mm x 100 mm grid cell were saved, with *z* coordinate as the average of the all points in that grid area. The grids were triangulated using 300 mm maximum length for each side. Finally, the points measured by the total station were compared with these points to determine Δz. Statistical analysis of the results is presented in Section 3.

3 RESULTS

Tab. 1. Vertical deviation (Δz) of the measured points (Stop & Go laser scanning system vs. the total station reference), with 20 m measurement intervals. Here, all observations included. Tolerance T = ±15 mm.

average	*x*	*[m]*	-0.001
standard deviation	*s*	*[m]*	0.008
min	*min*	*[m]*	-0.030
max	*max*	*[m]*	0.018
deviation below -15 mm	*n (<-T)*	*[n]*	10
deviation over +15 mm	*n (>+T)*	*[n]*	3
sample	*n*	*[n]*	319

Tab. 2. Vertical deviation (Δz) of the measured points (Stop & Go laser scanning system vs. the total station reference), with 20 m measurement intervals. Here, single points having more than tolerance T = ±15 mm deviations (13 points) were removed.

average	*x*	*[m]*	-0.001
standard deviation	*s*	*[m]*	0.007
min	*min*	*[m]*	-0.015
max	*max*	*[m]*	0.015
deviation below -15 mm	*n (<-T)*	*[n]*	0
deviation over +15 mm	*n (>+T)*	*[n]*	0
sample	*n*	*[n]*	306

Tab. 3. Vertical deviation (Δz) of the measured points (Stop & Go laser scanning system vs. the total station reference), with 30 m measurement intervals. Here, all observations included. Tolerance T = ±15 mm.

average	*x*	*[m]*	-0.003
standard deviation	*s*	*[m]*	0.009
minimum	*min*	*[m]*	-0.030
maximum	*max*	*[m]*	0.032
deviations less than -15 mm	*n (<-T)*	*[n]*	19
deviations over +15 mm	*n (>+T)*	*[n]*	6
total	*n*	*[n]*	248

Tab. 4 Vertical deviation (Δz) of the measured points (Stop & Go laser scanning system vs. the total station reference), with 30 m measurement intervals. Here, single points having more than tolerance T = ±15 mm deviations (25 points) were removed.

average	*x*	*[m]*	-0.002
standard deviation	*s*	*[m]*	0.006
minimum	*min*	*[m]*	-0.015
maximum	*max*	*[m]*	0.015
deviations less than -15 mm	*n (<-T)*	*[n]*	0
deviations over +15 mm	*n (>+T)*	*[n]*	0
total	*n*	*[n]*	223

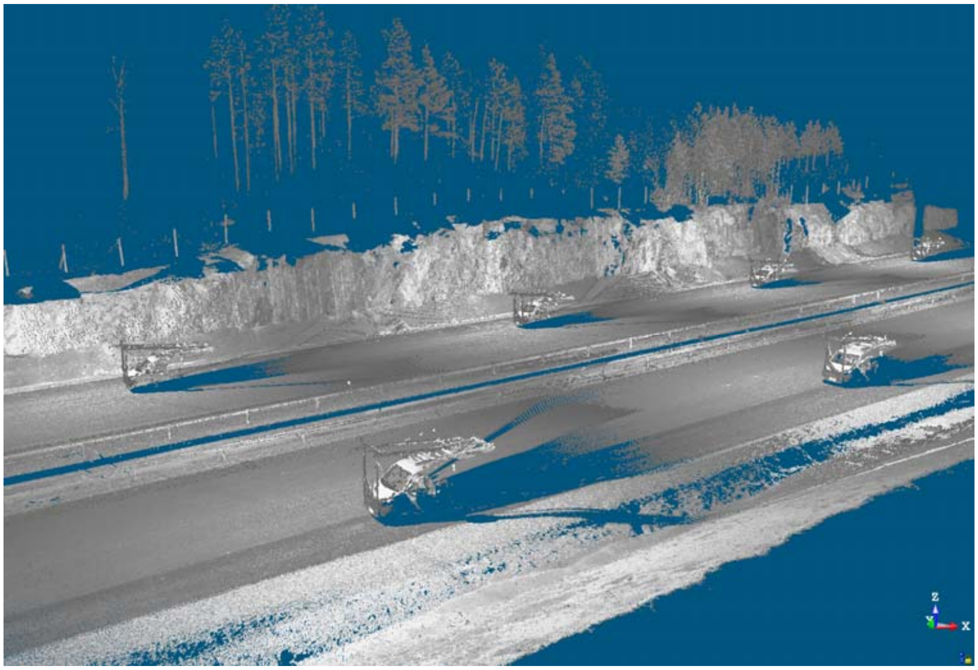

Fig. 8. An example of use of the laser scanning system in a design-build-maintenance-operate project of a Finland motorway.

4 CONCLUSIONS

Measurements were executed using 20 m or 30 m intervals between consecutive measurement stations. With 20 m intervals, the reference points were approximately 1 mm below the triangulated laser scan measurement surface. The standard deviation was 8 mm, so that the accuracy of the measurement was (–1 mm ± 8 mm). 96% of the points measured by the total station had less than ±15 mm deviation. If points with more than ±15 mm deviations were eliminated, the accuracy of the measurement was (–1 mm ± 7 mm).

When using 30 m intervals, the reference points were approximately 3 mm below the triangulated laser scan measurement surface. The standard deviation was 9 mm, so that the accuracy of the measurement was (–3 mm ± 9 mm). 90% of the points measured by the total station had less than ±15 mm deviation. If points with more than ±15 mm deviations were removed, the accuracy of the measurement was (–2 mm ± 6 mm).

Individual points deviating more than ±15 mm can in some cases be removed from other observations if the errors can be found to be gross errors. The measurement accuracy of the Stop & Go Scanning system can be found to be sufficient to the tolerance of ±15 mm when considering only relative accuracy.

In subsequent research, the accuracy results for Stop & Go Scanning will be compared to accuracy results for mobile laser scanning. In additional research, the measurement economy of Stop & Go Scanning vs. mobile laser scanning will be investigated. This evaluation will include both safety and efficiency components.

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