ROAD SURFACE SURVEYING USING TERRESTRIAL LASER SCANNER AND TOTAL STATION TECHNOLOGIES

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Abstract. This study compares the applications of two novel surveying technologies for road surface mapping - Terrestrial Laser Scanners and robotic Total Stations. In particular, a Leica HDS3000 and a Leica TCRP 1203 instruments were used. The principles of both technologies are reviewed and their applicability is discussed. The study deals with issues of road surveying under non-stop traffic condition, the safety of surveyors, work methodology, optimization of surveying time. The aspects of data processing, assessment, analysis and achieved accuracy are also handled. Possible reasons for detected discrepancies between different approaches are discussed in detail. The two methods in question both allow the accurate determination of paving material volumes that should be milled off the upper layer of the road surface and the volume of the filling material required to achieve a smooth road surface. However, the study indicates that using conventional surveying methods such as total station surveying in road surface mapping is more time consuming and the results are more generalized than using laser scanning technology where capturing thousands of surface points (i.e. point cloud) takes just seconds.

Keywords: Terrestrial Laser Scanner, mapping of road surface.

1. Introduction

This study compares two different ground profile surveying technologies and corresponding survey results. In particular, an emerging technology of the terrestrial laser scanning is compared with the conventional total station surveying. Both surveying technologies were tested on a 37 meter long road section over a bridge, which is located some 25 km west of Tallinn, the capital of Estonia.

In case of both road ground profile surveying technologies which were used, overviews of surveying equipment and technologies are given. Surveying duration and post-processed survey data is also analyzed in the study.

The study is based on survey data from the Mill (2008) study.

A study focusing on testing a terrestrial laser scanner in high-speed road survey and analyzing the smoothness of the road using laser scanning data was done by Chow (2007).

This study is described in eleven sections. The introduction is followed by a section on surveying principles of terrestrial laser scanning. The third section tackles road ground profile surveying. The fourth and the fifth sections give an overview of the surveying equipment used.

The sixth and seventh sections describe the surveying of a road using laser scanning and total station technology. Post-processing of the data is discussed in the eighth section. The ninth section compares the two surveying methods. The results of the study are discussed in the tenth section. A brief summary concludes the paper.

2. Surveying principles of terrestrial laser scanning

Based on the scanning technologies terrestrial laser scanners can be divided into two basic groups according to scanning technologies: time of flight laser scanners and phase-shift laser scanners.

There are many differences between time of flight laser scanners and phase-shift lasers scanners. In distance determination a phase-shift laser scanner sends out light waves of varying lengths to the target object. Some of the photons fade and some reflect back from the object to the laser scanner. Due to the differences in the oscillation of the waves which were sent out and the waves the reflected back in the opposite phase, a phase-shift arises. A phase shift is any change that occurs in the phase of one quantity, or in the phase difference between two or more quantities (Glen 2005). The distance of a survey point is determined using the size of the phase of phase-shifts (figure 1).
limeters. For example, the Leica HDS 3000 scanner uses a system of rotating mirrors; the horizontal direction of the laser rangefinder is changed by rotating the laser scanner itself around the vertical axis. While time of flight scanners can determine up to 1 000 000 points per second (Leica Geosystems 2010), then phase-shift laser scanners can determine up to 1 000 000 points per second (Zoller+Fröhlich 2010).

The duration of the scanning process is dependent on both the speed of determining distances and scanning resolution.

A terrestrial laser scanner scans its entire field of view one point at a time by changing the laser rangefinder’s direction of view to scan different points. The vertical direction of the laser rangefinder is changed by using a system of rotating mirrors; the horizontal direction of the laser rangefinder is changed by rotating the laser scanner itself around the vertical axis. While time of flight laser scanners can determine up to 50 000 points per second (Leica Geosystems 2010), then phase-shift laser scanners can determine up to 1 000 000 points per second (Zoller+Fröhlich 2010).

The difference in phase of two waves is known as the phase shift

In contrast, the time of flight laser scanners determine distances by measuring how long it takes for the pulse of light to reflect back from the object. Note that the distance is twice as long as the actual distance because the pulse of light moves forth and back. The distance is computed by (c · t)/2, where t is the round-trip time, and c is the speed of light. Time of flight scanner distance measuring accuracy is dependent on how precisely time (t) is measured, let it be said that for a pulse of light to travel one millimeter takes 3.3 picoseconds (3.3 · 10^-12).

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A major disadvantage with phase-shift scanners is their shorter measuring distances being typically less than 100 meters.

The main advantage of time of flight scanners is their long range, up to 1000 meters. The shortage of time of flight laser scanners is their relatively inaccurate time measurements. Distance measurement accuracy is in millimeters. For example, the Leica HDS 3000 scanner used in our study determines distances with an accuracy of ±4 mm.

3. Road ground profile surveying

Using studded tires in wintertime in temperate zones where overall average yearly temperature +5 °C is quite common. Inevitably using studded tires is the main cause of wear of asphalt cover. Wear and sagging are in turn the main cause of ruts in the road surface. Considered the fact that in temperate zones the amount of rainfall exceeds evaporation and temperatures fluctuate substantially around 0 °C. Consequently, the water in pavement cracks often freezes and melts, causing the formation of holes (water expands when frozen) (WSDT - State Materials Laboratory 2008).

Reconstruction of asphalt paving is usually accomplished by milling off the uneven top layer of the road cover and filling the holes and milled ruts with asphalt. For the reconstruction works, the existing road cover needs to be mapped beforehand. Usually the road surface model is created using total station survey data. To construct a surface model of a two lane road, cross profile points are measured from each side and from the centre of the road with a step of 10 meters in settlements and outside settlements where there are curbstones on road sides. In rural areas the cross profile points are measured with a step of 12. 5 meters. Requirements state that the longest sight distance on road profile mapping should not be greater than 150 meters. Errors in the surveying heights must not exceed ± 2 cm, with respect to the surveying network (Estonian Road Administration 2008).

As mentioned before, a total station is used for conventional road surveying. In this case a reflector prism is placed at each survey point. One of major disadvantages of this type of survey method is lack of detail in the surface model created. Let it also be mentioned that the shape of surface model produced depends much on where precisely the reflector prism pole had been placed, whether it had been placed on a level plane surface, or on a lower surface dent or on a higher hump. Therefore, the produced road surface model may not reflect in sufficient detail the depths of dents and the heights of humps. If such a micro-relief is needed by the conventional total station survey, then this may to greater overall resource costs.

A major problem in road surveying with a total station is the safety of surveyors, since it is very difficult to work on the road when it’s not closed down to traffic. Commuters on the road might not notice the surveyor. The risks are even higher when working on highways where safety is not ensured by the wearing of just a reflector vest or placement of safety cones.

Using a terrestrial laser scanner for road surface mapping does not require the need of road closure.

In order to compare two different technologies for road surface mapping, in June 2007 a terrestrial laser scanning and total station surveying were carried out. The work was accomplished using a Leica Terrestrial laser scanner HDS 3000 and a Leica total station TSRP 1203. As a result, two road surface models of the 37 m long strip crossing the bridge were created, one based on the laser scanning data and the other one on the total station survey data.

4. Terrestrial laser scanner Leica HDS 3000

The terrestrial laser scanner Leica HDS 3000 kit consists of software and hardware. The hardware side consists of a laser scanner, batteries, a 220 V adapter and a laptop which is used for controlling the scanning process and saving scanned data. Targets and target mounts
(figure 2) are also included in the hardware kit. Targets are determined from different scanning stations which are afterwards used to join all point clouds measured from different stations together.

The software side consists mainly of the program Leica Cyclone, which has a number of sub modules for scanning and for modeling. We can also include Bentley’s MicroStation and Autodek’s AutoCad with the plug-in COE (Cyclone Object Exchange) and Cloudworx for Microstation/AutoCad into the software set. COE is a plug-in which is used to exchange data between Cyclone and MicroStation or AutoCad. Cloudworx for MicroStation/AutoCad is a plug-in which is used to produce topographic plans or profiles in MicroStation or AutoCad drafting environments.

5. Total station Leica TCRP 1203

The total station Leica TCRP 1203 kit contains the total station, a reflector prism pole, a 360˚ reflector prism and a remote control.

The Leica TCRP 1203 is an instrument with an automated reflector prism tracking system and a remote control system. The reflector prism tracking system leaves out the need of precise sighting onto the prism. The Power Search software helps finding the prism if the connection between the total station and the prism is lost.

The remote control screen shows the same picture which is on the total station screen in real time. In addition, the remote control has a touch-screen and a full QWERTY keyboard. Controlling the total station via the remote control device is analogous to controlling the total station using the keyboard on the total station. All functions on remote control are the same as on the total station.

6. Scanning the road surface

The scanning process begins with observing the scanning area, determining the potential locations for the scanner and placing targets. The used Leica HDS 3000 terrestrial laser scanner determines 1800 points per second.

Scanning of the road strip was done from two scanner positions located at opposite sides of the bridge. One station was located at the southwest end of the bridge and the other at the northeast end of the bridge (figure 3). The entire scanning process took 2 hours and 40 minutes. Initially the survey data was collected in an arbitrary coordinate system. However, using control points which were coordinated with a total station, the point cloud was converted into the Estonian National 2D rectangular coordinate system L-EST 97, and the heights into the Estonian National height system Baltic 1977. A total of 1 394 426 points were gathered in scanning, 256 722 of which were used to create road surface.

7. Total station surveying

Surveying speed with a total station depends largely on traffic frequency. Namely the connection between the total station and the reflector prism can be interrupted easily by passing by vehicles; therefore, some of the points need to be remeasured. Surveying is complicated due to safety considerations because surveying points must also be determined on the centre of the road.

Road profile field works took 2 hours and 20 minutes altogether. To receive a detailed model of the surface of the road, the surface was measured with a step of approximately one meter in the longitudinal direction, while in the transverse direction five points were measured, two from both sides and one from the middle. Thus, the number of the points exceeds approximately 10 times the requirements of the Road Administration. From the 37 meter long road, a total of 244 points were gathered.

The entire measuring process was carried out without road closure (i.e. the same way as laser scanning).

Survey data is in the Estonian National planar coordinate system L-EST 97, while heights are in the Estonian National height system Baltic 1977 (i.e. in the same coordinate and height system as the laser scanning results).

8. Post processing of the survey data

All survey data processing was done using the Bentley MicroStation V8 drafting program.

Both the data gathered with the total station and with the laser scanner TIN (TIN - triangulated irregular network) triangulation models were produced. The TIN triangulation model is used because the surface of the road is uneven. The triangulation model is essentially a 3D representation of the roads’ surface created using the heights of survey points. Where heights increase gradually or where heights are even the triangular facets of the
network is larger; where the surface is more rugged the triangular facets of the network is smaller (figure 4). The edges of the triangles coincide generally in higher points and in lower points.

Fig 4. Fragment of TIN mesh model created using laser scanning data (Left-hand side), fragment of TIN mesh model created using total station survey data (right-hand side)

Contour lines intersecting after every 2 cm were added to both road surface models (figure 5).

Fig 5. Surface models with contour lines. Model created using laser scanner data (left-hand side) and model created using total station survey data (right-hand side)

9. Indirect comparison of survey methods

The terrestrial laser scanner Leica HDS 3000 works within a range of up to 300 meters. The effective measurement range depends on the surface to be scanned. Road surface is a relatively horizontal surface and if we place the scanner onto a tripod two meters from the ground, then the scanning range in one direction could be 60 meters, the angle of the laser beam in the horizontal direction is then 3° (therefore, we can scan easily up to 100 meters of road in one position). In total, the distance would be 120 meters, 60 meters in each direction. If we look at a two lane road which is approximately 11 meters in width, then the entire survey area would be 120 · 11 = 1320 m². Taking into account the fact that the scanning speed is up to 1800 points per second and the scanning resolution is 10 centimeters, then roughly scanning an area of 180 m² takes only a second and scanning a total area 1320 m² takes only 7.3 seconds. We must also consider that scanning area assignment is based on a dome shape photo image (full 360° · 270° dome). The scanning area selection is accomplished by selecting segment areas of the dome using degrees. Because a road is a line object then selecting the area just once is usually not enough, therefore prolonging the scanning process. Difficulties with assigning the scanning area might arise if the scanner is placed in the middle of the road, for instance, on an overpass, then selecting the scanning area is easier.

Specifications for the total station Leica TCRP 1203 indicate that the maximum range is up to 1000 meters. Determining reflector prism point takes 0.3 seconds in tracking mode, while the normal walking speed is 5 kilometers per hour, i.e., 85 meters per minute. If we determine the side points and centre point (three points in total) on a two lane road with a step of 10 meters, then the walking distance of the survey area is 120/10 · 11 = 132 meters. To walk a distance of 132 meters takes 1.6 minutes. Therefore, the surveying time for the 1320 m² area would come to roughly (12·3·0.3) + 1.6 = 12.4 minutes. If we consider traffic density, surveyors’ safety, the directing of the reflector prism, intermittent loss of the connection between the remote control and the total station, then the total survey time can increase significantly.

In conclusion surveying an area of 1320 m² with a laser scanner could be done in a matter of seconds, roughly calculated 7.3 seconds. Surveying the same area with a total station takes several minutes, roughly 12.4 minutes.

10. Comparing the results

To compare two different sets of survey data, the data was imported into the Bentley MicroStation V8 drafting program and two TIN surface models were created.

The model created using the total station survey data and the model created using laser scanning data were superimposed. The triangular meshes were activated and elevation difference command was executed. The program calculates within selected areas the differences in model heights and shows divergent areas using colors. We must keep in mind that when creating TIN meshes, the amount of survey points is crucial. Figure 6 illustrates the differences with contour lines between the two TIN meshes created. Blue contour lines illustrate the lower parts of the differences, white contour lines illustrate equal heights, and orange contour lines illustrate the higher parts. At the northeast and southwest ends the total station points are higher than the laser scanner points. Points with equal heights are scattered on the model. The biggest difference between heights is -8.1 centimeters at the southern corner of the model. The lowest difference between heights is +0.8 centimeters at the northern end of the model.

Fig 6. Comparison result of two TIN meshes. northeast direction is right

From the comparison model we can conclude that total station survey points appear to be lower than the laser scanner points, and this is probably caused due the
fact that the cross profile transverse gradient values are not constant given the unevenness caused by the state of wear and sagging of the paving surface and of the road. The total station survey points could be located on sags or on higher humps; therefore the model created using total station survey data is more generalized. At the same time the distance between laser scanner survey points is occasionally less than a centimeter producing highly detailed surface information.

11. Comparison the two surface models with a project surface

Using total station survey data a project surface of the road was created. The project surface has given the nature of the road in question a suitable longitudinal gradient 0.47% and a transverse gradient on two sides of 2.5% (figure 7). Comparing the project surface with surfaces created using laser scanner and total station survey data gives the amount of material that needs to be milled off the top layer of the road surface or the amount of filling material needed to smoothen the road surface.

![Fig 7. Project surface of the road](image)

Comparing the project surface with the model created using laser scanning survey data show that on the 37 meter long road strip the amount of material that should be milled off is 0.21 m³ and the amount of filling material to be used is 6.54 m³. Comparing the project surface with the model created using total station survey data shows that on the 37 meter long road strip the amount of material that should be milled off is 0.24 m³ and the amount of filling material to be used is 4.85 m³.

The results show surprisingly little differences in material quantities that should be milled off the road surface and material quantities that should be used to fill the road surface, even though laser scanning technology has a great advantage due to a larger amount of points. The differences could be due the fact that the total station survey was carried out ten times more densely than required. The differences amount to only 0.03 m³ of material that should be milled off the road surface and 1.69 m³ that should be filled along the 37 meter long strip.

12. Conclusions

Terrestrial laser scanners collect a large number of points from the observed object within a short period of time. The collected points make up a point cloud. The point cloud includes information about the scanned object, each point holding xyz coordinates, the RGB code, and the reflection intensity value. Point clouds are easy to use in various applications, beginning with just simple research and ending with different data processing operations such as modeling and designing.

The application areas of terrestrial laser scanning technology are increasing all the time. Every year there are newer and more efficient models introduced on the market. The latest time of flight laser scanners like the Leica C10 and Trimble CX 3D are capable of collecting up to 50 000 points per second (Leica Geosystems 2010, Trimble 2010). In comparison, the laser scanner used in this study is able to collect only up to 1800 points per second. The difference is nearly thirty times, this has a great impact on the working pace. Producers placed great emphasis on user friendliness, so there are fewer or no cables at all, while data transferring is carried out using Bluetooth, Compact Flash Memory Card or other similar means; there are no external batteries; and there is no need for a control laptop because controlling can be done on the scanner.

In the course of the study, two road surface models were created, one using total station survey data and the other laser scanner survey data. The model created using laser scanning data is several times more detailed than the model created using total station survey data due to the number of survey points.

If the road surface model is more detailed, then we can determine the optimal material quantities that should be milled off the surface of the road and the optimal material quantities that should be used to fill the road surface.

In conclusion we can state that primary advantages of using terrestrial laser scanning technologies in such working areas lie in the surveying speed, the safety of a surveyor, and the absence of a disruption to traffic. Laser scanning certainly provides advantages over total station surveying when surveying objects such as bigger roads, highways and tunnels (subways), when the closure of the object for surveying is out of the question or very complicated. The disadvantage of using terrestrial laser scanner is its dependence on the weather. Scanning work is not possible when it’s snowing and raining because the laser beams might reflect off from the snowflakes or rain drops.

References


