OPERATING QUALITY CONTROL OF GROUND MACHINES BY MEANS OF THE TERRESTRIAL LASER SCANNING SYSTEM

Tomáš Křemen, Milan Kašpar, Jiří Pospíšil

CTU in Prague, Faculty of Civil Engineering, Department of Special Geodesy, Thákurova 7, 166 29, Praha 6, Czech Republic - (tomas.kremen, kasparm, pospisil)@fsv.cvut.cz

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ABSTRACT:

In terms of research dealing with acceleration of technological and measuring processes during operating earth moving machines, a technological procedure of operating quality control of machines by means of the laser scanning system HDS 3000 was proposed which was used as a measuring means during DTM formation. With regard to the fact HDS 3000 is a terrestrial scanning system, the proposed solution concentrated especially on solving the issue of a small height of the scanner above the terrain, further on accuracy of the terrain shape determination during repeated measuring and on the overall accuracy of the measured terrain. The procedure of operating machines control proposed in such a way will be possible to use not only in the proceeding research, but also as one of other possibilities of control, eventually for documentation of the real state of performing the ground works.

1. INTRODUCTION

1.1 General Introduction

Within a research project dealing with acceleration of technological and measuring processes of construction and agricultural works with emphasis put on earthmoving machine control, the department of special geodesy is dealing with obtaining geodetic data and control of accomplished earthmoving works operated by construction machines.

1.2 Methods of Machines Control Systems

The measuring machines are currently controlled especially by means of ultrasound, satellite navigation, laser and total station (Kašpar, 2001). Their principles are briefly described in the following articles.

1.2.1 Ultrasonic Control: Earthmoving machine control by means of ultrasound is applied for finishers during laying upper layers of a roadway. The principle of this method is measuring distances to the working plane by ultrasound sensors placed on the machine and eventual following correction of smoothing lath position. When sensors for transverse slope are installed as well, it is possible to control not only height, but also transverse slope of finisher smoothing lath. Accuracy of laying the layer by an ultrasound control machine ranges in millimetres (c. 2-5 mm).

1.2.2 Satellite Control: The GPS system is currently used for machine control by means of satellites. The system consists of a reference station placed on a known point, which transmits GPS corrections from the GPS receiver(s) placed on the machine and of various propensity sensors. The reference station can be situated in distance of several kilometres from the machine without direct visibility and it can be used by several machines at the same time. Satellite control machine accuracy ranges in several centimetres (c. 1-2 cm).

1.2.3 Laser Control: The laser control machine system is used for example for terrain adjustment by graders, dozers or excavators. Its setting is suitable in a plane terrain. The system consists of laser sensors placed on the machine and of laser machines placed near the adjusted terrain. The laser machines create a guiding line (horizontal or sloping) or a guiding plane (horizontal or variously sloping). The machine can be also equipped with various tilt sensors. The principle of this method is observing a guiding laser beam with laser sensors, by means of which position of working machines is adjusted. Accuracy of terrain adjustment by means of laser ranges in millimetres (c. 5 mm).

1.2.4 Total Station Control: The total station control can be applied in a wide extent of earthmoving machines in a height more broken terrain. The system consists of a motorized total station placed at the adjusted terrain and of a receiver placed on the machine. The receiver consists of set of reflection prisms for observing the total station and of a receiver for reception of data transmitted by the total station. The principle of this method is comparing the current position of the machine with a project in real time of the total station and transmission of relevant corrections. Machine control accuracy by means of a total station ranges in millimetres (c. 2-5 mm).

1.3 Control surveying

Tachymetry by the total station, surface levelling, measuring lengthwise and transverse profiles or GPS measuring are most often used for terrain adjustment control. We used a terrestrial laser scanner in our experiment.

2. TERRESTRIAL LASER SCANNING TECHNOLOGY

2.1 Terrestrial Laser Scanning

Terrestrial laser scanning systems are a relatively new geodetic method used approximately in the last five years. They enable a contactless measurement on space subjects, their modelling and visualization. Most of them use the space polar method for determination of space position of detailed points, where lengths are measured by a pulse laser distance meter or by a phase distance meter and angles are determined from reading position of plane oscillating mirrors, prisms or from rotation of the total head of the scanner. During measuring, the scanner covers the object by a very thick network of detailed points in a regular angle interval, by so called point cloud. The individual measurements can contain from tens of thousands up to millions of detailed points (Kašpar, 2004).

2.2 Leica HDS 3000

Terrestrial laser scanning system used in this experiment is HDS 3000 from the Leica Company. It is a system that uses a pulse laser distance meter for measuring lengths and that determines angles by reading turning of oscillating plane mirror and of position of head of the scanner. The manufacturer states its extent 100 m and accuracy in position of one detailed point 6 mm for 50 m. The scanner field of view is 360º in horizontal direction and 270º in vertical direction.

2.3 Scanning Technology

2.3.1 Scanning Technique: The whole measuring process with the scanning system in terrain consists of suitable choosing stands of the scanner and of suitable placing identical points, which can be used for connection of measuring from individual stands into one unit or for transformation of the measured data into a particular system of coordinates. The service area and position of identical points is measured during the scanning system measuring itself. The identical points can be also measured by a total station, results of the measuring will be used as control of connection of the individual measurings into one unit and for placing into a suitable system of coordinates. The measured data are processed in the office afterwards.

Procession of the measured data takes place in special programmes determined for procession of point clouds. The measured data are purified from noise first (disturbing points measured on objects, which are out of our interest, vegetation, people passing, automobiles…). Then it comes to registration of the individual measurings into one final point cloud and eventual transformation into a suitable system of coordinates. The data are prepared for processing in this moment. The single parts of the cloud can be interlined with simple geometric configurations (plane, cylinder, cone…) or by a triangular network. In the created model it is possible to carry out various measurings and calculations or to export the model into various CAD programmes.

2.3.2Measurement Data Quality: The final measured data quality is influenced by many influences as internal scanner measuring accuracy, registration and transformation accuracy, geometric form of the measured area and physical properties of the scanned surface.

The internal scanner measuring accuracy is by accuracy of determination of the individual elements necessary for calculation of space position of the individual points. The stated angle accuracy of the HDS 3000 system is 0,06 mrad in both directions, the length measuring accuracy is 4 mm, so the final accuracy in position of the detailed point is 6 mm for 50 m distance.

When no identical points are used during registration, its accuracy is influenced by a geometric configuration coinciding in the area of the single connected clouds. This registration is more accurate if it is possible to identify easily several points in the coinciding area on the geometric configuration of the individual connected clouds and if the coincided area is formed suitably (for example coinciding area on a building facade, which contains various window wills, window and door holes). If the coincided area is not formed enough and if identical points on it are difficult to identify, the registration accuracy can sink significantly (for example big car park and airport plain) and it is suitable to use for registration identical points that would be suitably placed during measuring. If identical points are used, the registration accuracy and eventual transformation are influenced by identical point determination accuracy.

Geometric form of the measured area and physical properties of the scanned surface are significant factors that influence the measured lengths. Ideal geometric conditions for measuring lengths arise when incidence angle of the telemetric beam is zero. When the incidence angle grows it can come to a situation when determination accuracy of position of the detailed point sinks or the detailed point will not be measured at all. Whether the length will be measured is influenced by incidence angle and physical properties of the scanned surface, reflectivity, absorbability and permeability. If the total intensity of the falling radiation is E, intensity of the reflected radiation is R, the absorbed radiation is A and the permeabled radiation P, then according to the energy conservation law:

$$E = R + A + P \tag{1}$$

We will express reflectability, absorbability and permeability from this relation:

$$\begin{aligned} \rho &= R / E \\ \alpha &= A / E \\ \pi &= P / E \end{aligned} \tag{2}$$

Reflectability defined in such a way ρ expresses the total amount of the reflected radiation from surface is given for various types of surfaces (for example reflectability of polished silver is 90-95%). But for measuring lengths is important the amount of intensity of the reflected radiation falling on the telemetric sensor in the scanner and is several orders smaller than the whole intensity of the reflected radiation. How large part of the reflected radiation will fall into the telemetric sensor depends on the incidence angle, total size of R reflected radiation and on type of surface. The basic types of surfaces are diffusion and specular. Diffusion surface reflects the radiation proportionally into all directions. In visible spectre of the electromagnetic radiation it is for example plaster or chalk. Specular surface reflects most of the reflected radiation according to the radiation law. An example of specular surface is polished silver. In figure 1 there are reflection diagrams for diffusion and specular reflection.

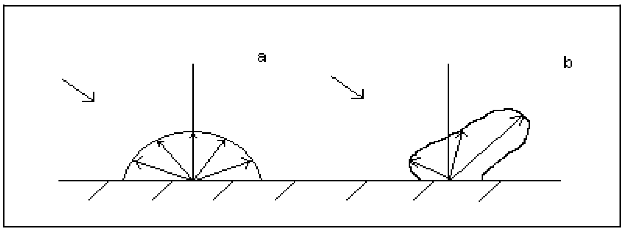

Figure 1. Reflection diagram a) diffusion, b) specular

From what was stated above it results that surface that is most suitable for measuring with the laser scanner is a diffusion surface with high reflectability, for which even in case of big incidence angles it comes to sufficiently big reflection of telemetric signal back to the scanner (Křemen, 2005). It relates especially to light surfaces with rough surface (in relation to wave length of the telemetric beam). Difficulties can arise for surfaces with high absorbability (dark surfaces), shining surfaces (specular reflection) and for surfaces with high permeability (glass).

2.3.3 Terrain Measurement: Before beginning the scanner measuring itself it is necessary to set several scanning parameters. Size and position of the scanner field of view (the area that will be measured) and scanning density. Scanning density for the HDS 3000 scanning system is defined as a horizontal and a vertical distance of neighbouring detailed points in a certain distance from the scanner.

For control measuring of a plane terrain (for example after adjustment with a dozer) a certain density of the detailed points measured on the surface is required. During setting the scanning density, a certain length interval is chosen for horizontal and vertical direction is chosen that will be kept in the set distance. The scanner transfers these length intervals into angle intervals and then it measures these similar points in this set raster. But distance of the detailed points in lengthwise direction measured on the scanner placed in a small height above terrain will be higher in the set distance. If the machine is placed in H height, the set distance for scanning density is D and amount of vertical interval is ΔR, then the distance of detailed points in lengthwise direction Δd is:

$$\Delta d = \frac{D * \Delta R}{(H - \Delta R)} \tag{3}$$

When we take this fact into consideration and set the vertical distance of the detailed points so that it complies with the required distance of the detailed points on the terrain, the detailed points nearer to the scanner will be measured much more densely. The volume of the measured data and time of the measuring itself will consequently grow. The HDS 3000 scanning system enables to set a sequence of scans where each scan will have its own set density of the detailed point and an extent of distances for which the measured data will be registered. This enables to prepare in advance this sequence of individual measurings on the basis of knowledge of the measured territory. The result will be measuring process automatization and reduction of measured data volume.

For connecting measurings from the individual stands in a larger territory it is suitable to use identical points because these points will also serve for placing the measuring into the required system of coordinates.

2.3.4 Postprocessing: At first, the individual scans are purified from all the disturbing points, until there are only points on the determined surface and identical points left. Then a registration and transformation of the individual scans into one final cloud in the required system of coordinates will follow. This final cloud is checked once more whether there still are not some points that are necessary to remove. In this moment, the cloud is prepared for creating the DTM (Digital Terrain Model) triangular network. This DTM is possible to be compared with the project and to judge its eventual deviations from the project. DTM can also serve as documentation of real state or a basis for the project.

3. EXPERIMENTAL MEASUREMENT

The accomplished experiment was measured on practical verification of using the HDS 3000 scanning system and for creation of DTM. The process of accomplishing the experiment was following. The chosen territory will be measured with the scanning system from two height levels. Identical points and check points proportionally spread across the measured territory will be measured by the Leica TC 1700 total station. Then a DTM will be created from measuring of the scanning system and height differences will be compared between DTM and control points determined by the total station.

3.1 The Place of the Experimental Measurement

The crossroads near the building of student cafeteria of the Faculty of Civil Engineering was chosen as a place suitable for experiment. Surface of the crossroads is covered with asphalt, there is no vegetation there and the surface is solid. Solidity of the surface and absence of vegetation were important, so that it would not come to undesirable changes of the surface during measuring the check points. Closeness of the student cafeteria building enabled measuring the crossroads from two height levels, cca 1,5 m and 6 m.

3.2 Procedure of measurement

After arriving in the service area, eight identical points were placed in the neighbourhood of the crossroads. The HDS 3000 was placed under gallery of the student cafeteria building up to the height of around 1,5 m above the surrounding terrain. The crossroads was measured from this position with three scans, the measuring parameters of which are stated in table 1. Then 8 identical points were measured with the scanner. This was an end to measuring with the scanner on this height level and the scanner was moved onto the student cafeteria gallery. Height of the scanner above the terrain on this height level was approximately 6 m above the surrounding terrain. The crossroads was measured with three scans from this position and the identical points were measured again. Parameters of measuring are stated in table 2.

Distance Interval [m]	Scanning density			
	Distance [m]	Horizontal spacing	Vertical spacing	Longitudinal spacing on terrain
0 - 11	10	200 mm	30 mm	200 mm
10 – 21	20	200 mm	15 mm	200 mm
20<	30	200 mm	10 mm	200 mm

Table 1. Scanning density and final lengthwise distance

Distance interval [m]	Scanning density			
	Distance [m]	Horizontal spacing	Vertical spacing	Longitudinal spacing on terrain
0 - 11	10	200 mm	98 mm	200 mm
10 – 21	20	200 mm	50 mm	200 mm
20<	30	200 mm	33 mm	200 mm

Table 2 Scanning density and final lengthwise distance

Measuring with the Leica TC 1700 total station was carried out then. 8 identical points and 144 check points on the crossroads surface were measured.

4. PROCESSING AND RESULTS

4.1 Processing of Measurements

4.1.1 Total Station: Measuring from the total station was processed in the Groma program. Position coordinates X, Y and height of all control and detailed points were determined.

4.1.2 System HDS 3000: Processing measuring from the scanner was carried out for each height level separately in the Cyclone program. At first, registration and transformation of the measured clouds from the height level 1,5 m into the coordinate system of identical points determined by the total station was carried out. Then purge of the final cloud from all the disturbing points, passengers passing, automobiles, road signs etc. was accomplished. The cloud purified in such a way was interlined with mesh TIN (Triangular Irregular Network). Points from the control measuring were imported into the created network and the height difference between the TIN mesh and check points was determined. The same procedure was used also for processing the measuring from the other height level.

4.2 Results

Results of this experiment are height results between check points and the created TIN mesh. Height determination accuracy with the Leica TC 1700 total station is 0,2 mm for 30 m distance with approximately horizontal sight. Accuracy of the HDS 3000 scanner in position of the detailed point for 50 m distance is 6 mm, length measuring accuracy is 4 mm. From this fact it results that the accuracy in the height of the detailed point is approximately 2 mm for 30 m distance with approximately horizontal sight. Considering that measuring with the TC 1700 total station is ordinally more accurate, it can be taken for error-free in relation to measuring with the HDS 3000 scanner.

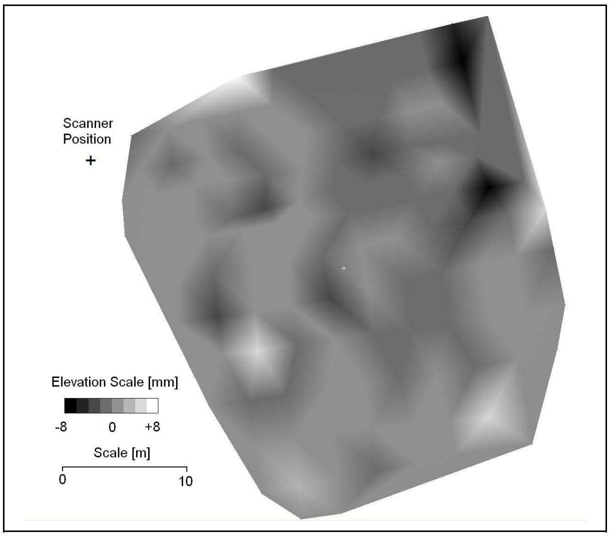

Figure 2. Distribution of height differences

For comparing the heights between DTM a check measuring, 122 check points in height level 1,5 m and 115 check points in height level 6 m were used. Height difference between measuring and DTM was calculated from the relation:

$$\Delta h = h_t - h_s \tag{4}$$

where Δh is height difference, h_t is height of the check point and h_s is height of the TIN mesh in the position coordinates identical with the position coordinates of the check point. In figure 2 we can see distribution of the height differences in height level 1,5 m.

The average height difference Δh_p and the standard deviation of height differences $\sigma_{\Delta h}$ from the following formulas were determined from the height differences for each height level:

$$\Delta h_p = \frac{\sum_1^n \Delta h}{n} \tag{5}$$

$$\sigma_{\Delta h} = \sqrt{\frac{\sum_1^n \Delta h^2}{(n-1)}} \tag{6}$$

where n is number of the used check points. The achieved results are stated in table 3:

Height level	Δh_p	$\sigma_{\Delta h}$
1,5 m	-0,2 mm	2,0 mm
6 m	-1,9 mm	2,8 mm

Table 3. The achieved results

From the results stated in table 3 it is obvious that the standard deviation of height differences did not exceed the marginal height difference for the HDS 3000 scanning system. The average height difference v in the height level 6 m shows that measuring of the scanner on this height level is probably loaded with a systematic error.

Influence of large incidence angle (around 90 gon) of the telemetric beam falling on the roadway surface on measuring accuracy of the HDS 3000 scanner was not proved.

5.CONCLUSION

The results of the accomplished experiment showed, that the HDS 3000 scanning system can be used for obtaining data for creation of DTM serving as a basis for automatic control of earthmoving machines, for which accuracy of earthmoving works 10 mm is required, and as a check method of accomplishing earthmoving works. The HDS 3000 scanning system can be used for most earthmoving machines (except the road finisher), where the expected accomplishment accuracy ranges around 10 mm.

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6.REFERENCES

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