INFLUENCES OF RANGE AND INCIDENCE ANGLE ON MEASUREMENTS OF A FULL-WAVEFORM TERRESTRIAL LASER SCANNER VZ - 400

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ABSTRACT

Full-waveform terrestrial laser scanning is a recent technology which is able to digitize and record the complete waveform of the backscattered echo. It gives additional information about the structure and physical backscattering properties of the illuminated surface (reflectance and geometry). Some authors focus on the data quality of a terrestrial laser scanner. Some of them are interested in the influence of the materials on the measurements of a full-waveform terrestrial laser scanner. Most of them are interested in the geometrical accuracy of the scanner (errors of instrumental axis, range accuracy using target, etc.). The aim of this article is to find out the influences of target geometry on the measurement of the full-waveform terrestrial laser scanner VZ – 400. The emphasis was put on the influence of range to target and incidence angle.

Key words: *Full-waveform terrestrial laser scanner, range, incidence angle, amplitude, reflectance*

1 INTRODUCTION

During the last few years, terrestrial laser scanning has become a standard method of data acquisition in close range domain. Conventional terrestrial laser systems do not record the structure of the reflected waveform. Furthermore, full-waveform terrestrial laser systems (FW – TLS) capture and digitize the full structure of the waveform of the reflected laser pulse providing more measures of change than only range. Laser scanning is mainly used in urban and vegetated areas.

Hartzell et al. introduced [1] that for a given Lidar system the return signal strength was directly influenced by atmospheric effects, range to target, surface reflectance and target incidence angle of the incoming radiation.

Carrea et al. described [2] that the intensity values recorded by TLS depended on follow parameters: laser beam wavelength, emission power, beam opening angle, system attenuation and internal calibration, scanned surface, range, incidence angle, surface composition and moisture content.

The aim of this article is to find out the influences of target geometry on the measurement of the FW – TLS. The realized experiments were focused on how the different range (i.e. the distance from scanner to the target) and different incidence angle (i.e. the angle between the incident laser beam and the normal vector to the scanned surface) influence the measurements of the full-waveform terrestrial laser scanner VZ – 400.

2 THEORY

Wagner used [3] the radar equation defining the received signal power (P_r) as follows:

$$P_r = \frac{P_t D_r^2}{4\pi R^4 \beta_t^2} \eta_{sys} \eta_{atm} \sigma_{cross} \qquad \text{(Equation 1)}$$

where P_t is the transmitted pulse power in watts, D_r is the device receiver aperture in meters, β_t is the laser beam width in radians, R is the range i.e. distance from the scanner to the target in meters, η_{sys} is the system transmission efficiency for TLS optical components, η_{atm} is the atmospheric transmission factor and σ_{cross} is the target cross-section in square meters.

Assuming that the target is larger than the laser beam and that its surface is a perfect diffuse reflector, the cross-section σ_{cross} is:

$$\sigma_{cross} = \pi \rho_\lambda R^2 \beta_t^2 cos\alpha \qquad \text{(Equation 2)}$$

where ρ_λ is the reflectivity of the surface for a defined wavelength λ and α is the incidence angle.

By substituting σ_{cross} in Equation 1, the simplified radar equation is:

$$P_r = \frac{P_t D_r^2 \rho_\lambda cos\alpha}{4R^2} \eta_{sys} \eta_{atm} \qquad \text{(Equation 3)}$$

The radar equation can be re-written that the received signal power P_r is proportional to the reflectivity index and the cosine of the incidence angle and inversely proportional to the square of the range:

$$P_r \propto \frac{\rho_\lambda cos\alpha}{R^2} \qquad \text{(Equation 4)}$$

3 FULL–WAVEFORM TERRESTRIAL LASER SCANNER

The full-waveform terrestrial laser scanner VZ – 400 manufactured by Riegl was used for the experiments. The VZ – 400 relies on the principle of pulsed time of flight measurement and applies echo digitization and online waveform processing. Specifications for the scanner are given in Table 1.

Parameter	**Long Range Mode**	**High Speed Mode**
Effective pulse rate	42 000 Hz	122 000 Hz
Max. measurement range (reflectivity 90%)	600 m	350 m
Max. measurement range (reflectivity 20%)	280 m	160
Minimal range	1,5 m	
Range accuracy	5 mm	
Range precision	3 mm	
Beam divergence	0,35 mrad	
Angular resolution	0,0005°	
Horizontal scanning range	0° up to max. 360°	
Vertical scanning range	Up to 100° (+60/ -40°)	
Laser wavelength	1550 (near infrared)	

Tab. 1 Specifications of VZ – 400 [4]

The resulting data for a single measurement point are the coordinates X, Y, Z, the amplitude, the reflectance and the deviation. The parameters are described [4] as follows.

The VZ – 400 provides a calibrated **amplitude** value scaled in decibels (dB). The calibrated amplitude is a signal strength property of the received optical target echo signal. It is defined as the ratio of the actual detected optical amplitude versus the detection threshold.

The **reflectance** is the ratio of the (measured) calibrated amplitude value of the target echo to the calibrated amplitude value of a diffusely reflecting white target at the same distance, orientated orthonormal to the beam axis and with a size in excess of the laser footprint. The reflectance is a distance independent property of the target surface reflectance with respect to a white target. The actual reflectance is given in decibels (dB). The reflectance is always a positive real number. Negative values indicate diffusely reflecting targets, whereas positive values are usually retro – reflecting targets.

The **deviation** is a property describing the change of the received echo pulse shape compared to the emitted pulse shape. Deviation 0 is the ideal case and means no distortion and the received pulse fits 100% to the emitted pulse.

The values of the amplitude and reflectance were used to describe the results of the experiments.

4 TEST CONFIGURATION

The experiments were performed two times (March and November 2016) in a hall of the Institute of Geodesy in Brno. Two wooden boards from different fruit trees were set as the diffusely reflecting target.

Fig. 1 Measuring of the targets in a hall of the Institute of Geodesy in Brno (March 2016)

The first experiments consisted of range to target influence. The distance between the scanner and the wooden board varies from 5 m to 40 m in 5 m increments. See Figure 2.

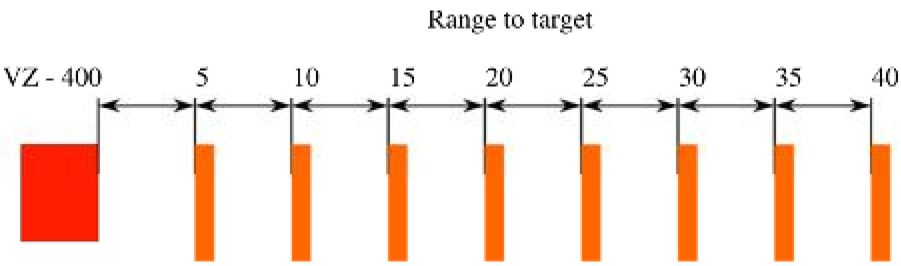

Fig. 2 Principle of the measuring of range

The second experiments consisted of incidence angle influence. The wooden board put on the table was scanned at a distance of 5 m. See Figure 3.

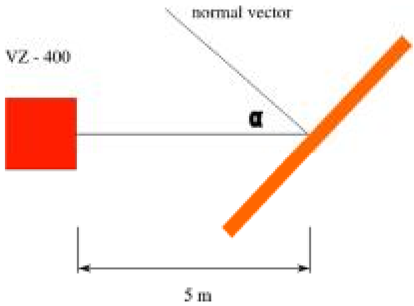

Fig. 3 Principle of the measuring of incidence angle

The mean values of amplitude and reflectance and their standard deviation were computed for each range and inclination angle and then compared to each other.

5 ANALYSIS OF RANGE TO TARGET

The range is defined as the distance from scanner to the target. The target wooden board was placed at distance from 5 m to 40 m in 5 m increments. According to the radar equation the amplitude should be inversely proportional to the square of the range.

The highest value of the mean amplitude was 36,8 dB (wood 1) and 35,0 dB (wood 2) at a distance 10 m. The lowest value of the mean amplitude was 27,5 dB (wood 1) and 25,5 dB (wood 2) at a distance 10 m. The standard deviation of amplitude for these ranges varied from 0,53 dB for the 5 m distance (wood 1) to 1,67 dB for the 25 m distance (wood 2). See Figure 3.

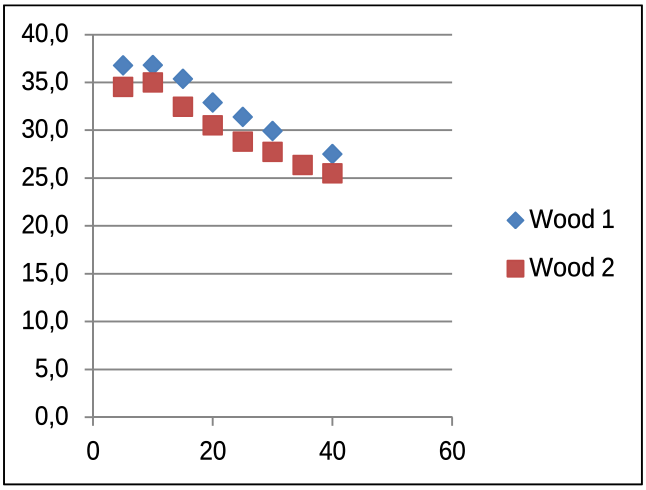

Fig. 4 Mean amplitude values for range to wooden boards (dB)

The reflectance is distance independent as was mentioned. Table 2 shows the values of reflectance for ranges from 5 m to 40 m. The values of reflectance lie in the same domain. The standard deviation of the reflectance achieves values of differences between particular values of mean reflectance. The standard deviation of reflectance varies from 0,62 dB to 1,67 dB.

Range [m]	Reflectance [dB]	
	Wood 1	Wood 2
5	0,2	2,4
10	0,1	2,0
15	0,1	2,8
20	0,5	2,9
25	0,3	3,0
30	0,5	2,6
35		2,7
40	0,3	2,3

Tab. 2 Mean reflectance values for ranges to wooden boards (dB)

6 ANALYSIS OF INCIDENT ANGLE

The incidence angle is defined as the angle between the incident laser beam and the normal vector to the scanned surface. The incidence angle is always in the interval from 0 to $\frac{\pi}{2}$. When a laser beam hits a diffuse reflective target, the return signal intensity decreases proportionally to the cosine of the incidence angle.

The wooden board put on the table was scanned at a distance of 5 m at six different incident angles. Table 3 shows the values of mean amplitude and mean reflectance.

Inclination angle [Grade]	**Amplitude [dB]**	**Reflectance [dB]**
8	36,3	0,7
18	35,1	1,8
38	33,7	3,2
58	31,9	5,1
72	30,0	7,0
86	26,7	10,3

Tab. 3 Mean amplitude and reflectance values for incident angles

The highest value of the mean amplitude was 36,3 dB for 8 grade and the lowest was 26,7 dB for 86 grade. The standard deviation of amplitude for these incident angles varied from 0,73 dB for 8 grade to 1,10 dB for 86 grade.

The values of reflectance increased with the inclination angle. The mean value of reflectance was lowest at 0.7 dB for 8 grade and highest at 10.3 dB for 86 grade. The standard deviation of reflectance varied from 0,73 dB for 8 grade to 1,10 dB for 86 grade.

7 CONCLUSION

The influences of range to target and incident angle on the measurement of the full–waveform terrestrial laser scanner VZ – 400 were presented in this paper.

The mean values of amplitude are dependent of the range. The amplitude decreased from the range 15 m, as expected. The similar behaviour was presented by Carrea et al. [1] who used the lasers an Optech ILRIS-3D^{ER} and an Optech ILRIS-LR.

The mean values of reflectance are independent on the range as was described in [4]. The mean values of amplitude and reflectance are dependent on the inclination angle. Their values decreased proportionally with the increase of inclination angle.

In the future these tests should be repeated with other types of terrestrial laser scanners.

Acknowledgment

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Literature

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