TECHNICAL SCIENCES
Abbrev.: Techn. Sc., No 16(1), Y 2013

PRACTICAL VERIFICATION OF THE PHONG REFLECTION MODEL CONDUCTED WITH THE USE OF TERRESTIAL LASER FIELD SCANING DATA

***Kamil Kowalczyk*[1*], *Jacek Rapiński*[2], *Dariusz Tomaszewski*[2]**

[1] Chair of Land Surveying and Geomatics
[2] Institute of Geodesy
University of Warmia and Mazury in Olsztyn

Received 25 May 2012; Accepted 4 March 2013; Avilable on line 10 July 2013.

K e y w o r d s: intensity parameter, reflectorless measurements, laser scanning, Intensity modeling.

A b s t r a c t

This paper is devoted to a practical verification of applying the Phong model, conducted based on available survey data obtained in field conditions. This model has already been described in previous articles, in which authors, using surveys performed in laboratory conditions, showed how to change the shape of the Phong model function depending on the material on which the laser beam falls. In subsequent publications, the focus was on the relationship between the incidence angle and the maximum distance that can be measured by the rangefinder. The measuring data were obtained as a result of scanning the furnace wall in the heat and power station in Pruszków, Poland with the use of reflectorless laser. The presented way of computation has been substantiated on the basis of calculated quantities, incidence angle and empirically defined parameters of the Phong model.

Introduction

Together with the technological advancements there appeared some new ways of taking observations that are successively being implemented into geodesy. In contemporary engineering surveys, reflectorless measurements are becoming more and more popular, allowing to shorten the time of obtaining stable results and increasing the number of data. These techniques have been fundamentally divided into two groups, Airborne Laser Scanning (ALS) which is based on placing the laser scanner on an airborne platform

* Corespondence: Jacek Rapiński, Instytut Geodezji, Uniwersytet Warmińsko-Mazurski, ul. M. Oczapowskiego 1, 10-719 Olsztyn, tel. 48 89 523-42-04, e-mail: jacek.rapinski@uwm.edu.pl

and Terrestrial Laser Scanning (TLS) where the device is placed on land surface.

The survey techniques mentioned above make use of a laser beam to determine the distance. An important issue then is a process of finding the farthest range which can be measured with the use of the given equipment. The main parameter considered for determining the maximum rangefinder range is the intensity. This quantity depends directly on the fraction of energy, which returns to the device after it is reflected off the object. There are numerous factors that affect the maximum measured range and the accuracy of taken observations. Intensity of a laser beam, however, depends directly on the atmospheric conditions, incidence angle, wave length, and the kind and color of substance from which the beam was reflected (KOWALCZYK, RAPIŃSKI 2011).

In the earlier publication (KOWALCZYK, RAPIŃSKI 2011) the authors introduced the theoretical Phong reflection model in laboratory conditions, proving the legitimacy of using it for modeling the maximum rangefinder range. The described model is mostly used in 3D computer graphics for determining some mirror reflections of imperfect objects. This model also allows for revealing the relations between the incidence angle of a laser ray and the partial energy that returns to the rangefinder.

The main objective of this paper is a practical verification of applying the Phong model, which will be conducted using available survey data, obtained in field conditions.

Registered energy and maximum rangefinder range

The measurements taken with TLS (scanners) can be considered in a similar way as those obtained by radars (SOUDARISSANANE et al. 2011). On the basis of this assumption, it is possible to derive a formula describing the amount of energy that returns to a rangefinder (1) (SABATINI, RICHARDSON 2010), later on referred to as the laser range equation:

$$P_R = \frac{\sigma D^4{}_{\mathrm{atm}}\ \tau_{\mathrm{sys}}\ P_T}{16R^4\,\lambda K_a^2} \tag{1}$$

where:

P_R – recived Signal Power (Intensity),

P_T – tramsmitted Power (Intensity),

σ – effective target cross section,

K_a – aperture illumination constant,

R – range from system to target,
λ – wavelength,
D – aperture diameter,
τ_{atm} – atmospheric transmission factor,
τ_{sys} – system transmission factor.

While analyzing equation (1), one can observe that the influence on the total returned energy have factors that result from direct measurements conditions i.e. range from system to target, atmospheric transmission factor τatm and geometric conditions being the consequence of locating the device. The next crucial element for the initial intensity value is the construction of survey equipment, however, assuming that the same device is used, such effects values can be acknowledged as constant. A significant factor that affects the final result as well, is the effective target cross section σ, due to the fact that it is a quantity that describes the properties of a target (2) (VAIN et al. 2011).

$$\sigma = \pi \rho R^2 \beta_t^2 \cos \alpha \tag{2}$$

ρ – reflectance of the target surface;
R – range from system to target;
β_t – beam width
α – incidence angle (angle between incoming laser beam and surface normal).

After applying some appropriate conversions and assuming that the whole beam has been reflected, the final formula for the range value is as follows (3):

$$R = \sqrt[4]{\frac{\rho D^2 \ \tau_{atm} \ \tau_{sys} \ P_T}{8 P_R}} \tag{3}$$

While taking measurements, the influence of the atmospheric conditions τ_{atm} has been omitted because the survey was conducted in a heat and power station, in which the temperature, humidity, etc. remained constant.

Theoretical Phong model

A fundamental model, specifically defined in physics, for determining the intensity of light reflected off the object, is the model developed by Lambert in 1760. Assuming that the model reveals a reflection from an ideal diffusely reflecting surface, the possibility of applying it in practice is restricted. Taking into account a diversity of materials from which the objects, that the laser beam falls on, are made, one needs to apply some more advanced way of calculation. Due to the applied modifications, a theoretical Phong model constitutes an expansion of Lambert's idea, allowing to reflect the ray off secular surfaces. It is assumed that the returning beam of light satisfies the following equation (4) (ASHIKHMIN, SHIRLEY 2000):

$$I = I_i[k_d \cos \Theta + k_s \cos^n \Phi] \tag{4}$$

where:

- I – the intensity of the reflected beam,
- I_I – the intensity of the incidence beam,
- k_d – the amount of beam that is diffused,
- k_s – the amount of beam that is reflected,
- Θ – incidence angle,
- Φ – the angle between incidence angle and the viewer direction,
- n – parameter describing the luminance of the material.

According to the Phong reflection model assumption, the final intensity value of the returning light, depends on the physical properties of the reflecting object, geometric measurement conditions and the incidence intensity value. The variables k_d, k_s and n are the quantities which make it possible to describe the influence that material has on the equation result. By correctly defining these parameters, it is possible to explicitly determine the influence of a reflecting surface type, color and structure (Fig. 1, 2, 3).

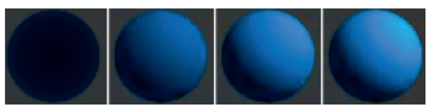

Fig. 1. Sample values of k_d parameter varying according to reflecting material

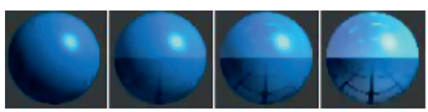

Fig. 2. Sample values of k_s parameter varying according to reflecting material

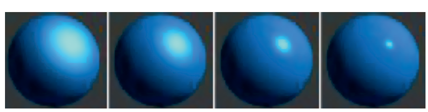

Fig. 3. Sample values of n parameter varying according to reflecting material

The incidence angle and the angle between incidence angle and the viewer direction allow for taking into account the influence of the geometry of a falling laser beam. In case of a laser scanning the Φ angle is the same as the incidence angle. In Figure 4 shape of the considered function graph is shown in a polar coordinate system. In order to obtain such shape of the Phong model function the authors used as parameters values $n = 60$, $k_d = 0.2$ and $k_s = 0.8$.

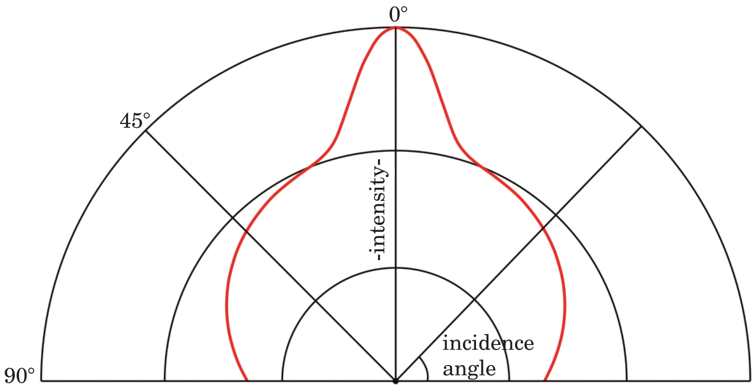

Fig. 4. Representation of the Phong function in a (polar) coordinate system

Testing the Phong reflection model in practice

As has already been stated in the introduction, this paper is devoted to the practical verification of the Phong model, conducted on the basis of field survey data. In order to perform this task, a set of points resulting from the laser scanning of the shield of a furnace in the heat and power station in Pruszków, Poland was used (Fig. 5).

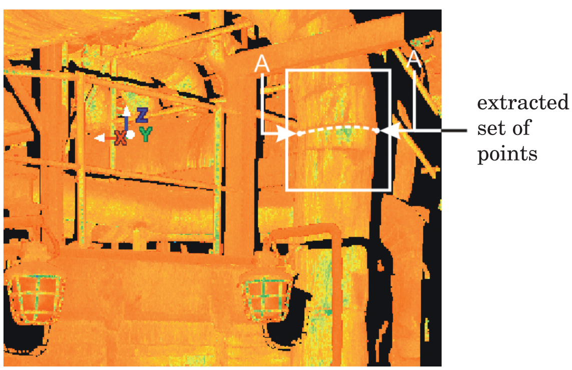

Fig. 5. Fragment of a point cloud representing the furnace in heat and power station

Result files from taken surveys contain coordinates (*X, Y, Z*) and intensity value for each point. In the cloud fragment presented above, one can see a heating pipe. Due to its cylindrical shape, a laser beam falling on such object, is reflected off different angles. This variability in incidence angle is considerably higher than in the case of flat surfaces. Making use of this property, a representative heating pipe had been chosen, from which, with the help of a surface perpendicular to the pipe direction, a set of points was extracted for later use (Fig. 6).

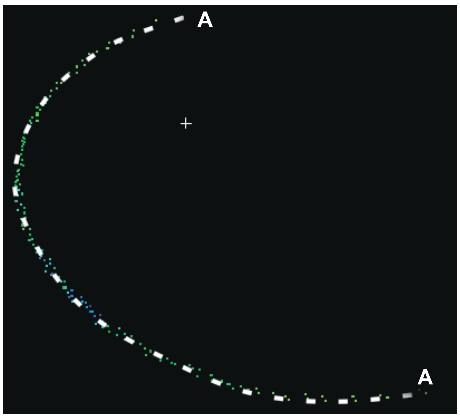

Fig. 6. Extracted set of points on a heating pipe

The next essential step for the Phong model realization was connected with finding the value of the incidence angle to each of the points. In order to achieve that, a curve was adjusted to the set of points. The root mean square error of the curve fit was equal 0.003436 m. Afterwards, normal and incidence angle were calculated for each of the points (Fig. 7). In such a way, all the quantities needed for performing the computation were collected.

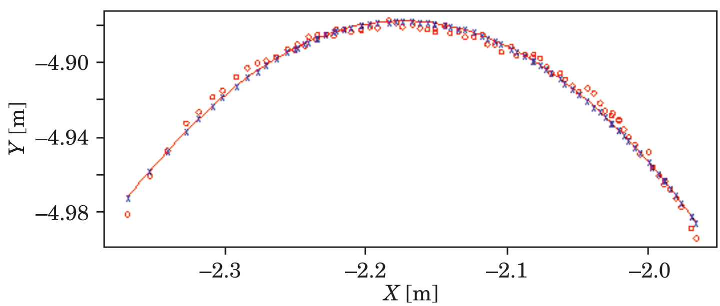

Fig. 7. A curve adjusted to a distinguished set of points

Results

The quantities, received as a result of the taken measurements and calculations, were used for drawing a suitable graph in the polar coordinate system. The way it was performed is analogous to the previous example (see Fig. 1). The task concerning the adjustment of the Phong model to the final function graph was carried out by an appropriate software. In this algorithm, the shape of the curve depended directly on the appropriate modification of the following parameters: k_d – the amount of beam that is diffused, k_s – the amount of beam that is reflected and n – luminance. The visualization of the Phong model function was graphically fitted to the extracted data set presented in the same polar coordinate system (Fig. 8). The variables were introduced based on physical properties of the substance from which the heating pipes had been made.

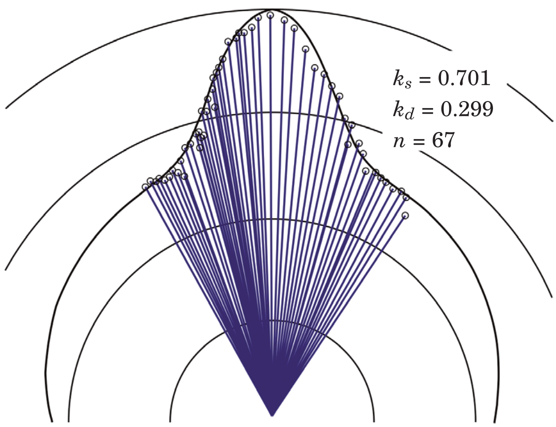

Fig. 8. Phong model adjusted to the measuring data

In the figure above, blue lines illustrate the survey data while a reflection curve is painted in black. The results clearly show that the Phong model can be used for reflectorless measurements. According to the findings obtained during some previous laboratory research (KOWALCZYK, RAPIŃSKI 2011), it can be concluded that in the case of matt substances, k_d – the amount of beam that is diffused, is considerably higher than k_s – the amount of beam that is reflected.

Conclusion

The results of the conducted research prove the legitimacy of the Phong reflection model used for picturing the intensity of returning a laser beam and maximum rangefinder range. The quantities obtained in the field conditions explicitly confirm the correctness of earlier laboratory research (KOWALCZYK, RAPIŃSKI 2011). This experimental way of determining the quantities k_s, k_d and n, for many substances, can later be used for establishing the physical properties of surfaces measured in terrain. Correct modeling of reflectorless surveys may constitute a new source of information taken into account while determining the border range measured by a given rangefinder.

Translated by DARIUSZ TOMASZEWSKI

Reference

ASHIKHMIN M., SHIRLEY P. 2000. *An Anisotropic Phong BRDF Model*. Journal of Graphics Tools, 5(2): 25–32.

RAPINSKI J., KOWALCZYK K. 2011. *The modelling of a reflectorless range finder maximum range with Phong model*. Reports on Geodesy. No.1 (90), Warszawa.

RAPINSKI J., KOWALCZYK K. 2011. *Verification of theoretical phong modelin reflectorless surveys.* Technical Sciences, 14(2): 255–261.

SABATINI R., RICHARDSON M.A. 2010. *RTO-AG-300-V26 Airborne Laser Systems Testing and Analysis*. NATO Research and Technology Organization.

SOUDARISSANANE S., LINDENBERGH R., MENENTI M., TEUNISSEN R. 2011. *Scanning geometry: Influencing factor on the quality of terrestrial laser scanning points.* ISPRS Journal of Photogrammetry and Remote Sensing, 66: 389–399.

VAIN A., LIBA N., SEPP K. 2011. *Factors affecting the airborne laser scanning intensity data.* Environmental Engineering, 3: 1511–1515.