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VERIFICATION OF THEORETICAL PHONG MODEL IN REFLECTOR LESS SURVEYS

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Key words: range finder, intensity, laser scanning.

Abstract

This paper presents the verification of Phong model used for reflector-less surveys. The model presented in (RAPINSKI, KOWALCZYK 2011) is compared with survey data. In order to obtain survey data the experiment with authors own testing device and software was performed. Data from the experiment was used to show the model parameters for various materials. The coefficients describing the model are: the fraction of light that was scattered, the fraction of light that was reflected and the luminance coefficient.

WERYFIKACJA TEORETYCZNEGO MODELU PHONGA W POMIARACH BEZLUSTROWYCH

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Słowa kluczowe: dalmierz, parametr intensity, skaning laserowy.

Abstrakt

W artykule przedstawiono weryfikację teoretycznego modelu Phonga w pomiarach bezlustrowych. Model opisany przez RAPIŃSKIEGO i KOWALCZYKA (2011) zweryfikowano z wykorzystaniem danych pomiarowych. W celu pozyskania tych danych przeprowadzono eksperyment zaprojektowanym przez autorów urządzeniem pomiarowym oraz autorskim oprogramowaniem. Na podstawie danych pomiarowych określono parametry modelu dla różnego typu materiałów. Parametry (współczynniki) opisujące model to część wysłanego światła lasera, która uległa rozproszeniu, część wysłanego światła lasera, która uległa odbiciu, oraz współczynnik opisujący luminancję.

Introduction

In modern civil engineering reflector-less surveys and laser scanning are continuously gaining attention. These techniques use laser beam to measure distance. There is a lot of effects that impact the distance measurement accuracy, maximum range and value of the intensity parameter. The fraction of laser light that returns to the range finder is conditional upon material type and color, incidence angle, laser wavelength and atmospheric attenuation (KOWALCZYK, RAPINSKI 2011).

In (RAPINSKI, KOWALCZYK 2011) authors described the proposition of use of theoretical Phong model for reflector less range finders maximum range. Although in theory this model seems to be appropriate it needs verification. The Phong model, used in computer 3D graphics, was adapted to model the maximum range of the range finder. This model describes the dependency of the incidence angle on the fraction of the returned laser light.

Practical verification of this model in real survey environment would be difficult due to large number of required observation, influence of not modeled effects (like atmospheric attenuation). In addition it is difficult to find an object with enough free space available for surveys (maximum range of modern equipment is in the range of few hundred meters). The verification was conducted in the laboratory environment.

The main goal of this paper is to verify the use of Phong model for maximum range and intensity parameter modeling.

Intensity and maximum range

Both intensity and maximum rage are dependent on the fraction of power of laser beam that will return from the target. The laser range equation describes the dependency between transmitted and received laser beam power (SABATINI, RICHARDSON 2010):

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

where:
P_R – received signal power;
P_T – transmitter power;
σ – effective target cross section (m^2);
K_a – aperture illumination constant;
R – system range to target (m);

λ – wavelength (m);
D – aperture diameter (m)
τ_{atm} – atmospheric transmission factor;
τ_{sys} – system transmission factor.

Assuming that the entire beam will be reflected, equation (1) becomes (KRUAPECH, WIDJAJA 2010):

$$P_R = \frac{\rho D^2 \tau_{atm} \tau_{sys} P_T}{8R^2} \tag{2}$$

where ρ stands for the target reflectance.

Deriving R from the equation 2 gives:

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

In the equation 3, D2, τ_{sys} and the ratio P_R/P_T are constant for a certain instrument. The term τ_{atm} depends on the atmospheric extinction coefficient, and is constant for the atmospheric parameters during the survey.This parameter was neglected in further considerations since it was constant in laboratory environment.

Phong model

In theory, the laser beam reflection can be either specular reflection, diffuse reflection or retro reflection. In practice most reflections are a combination of specular and diffuse. Phong model divide the amount of light reflected in these two ways in two coefficients: k_d – the amount of beam that is diffused and k_s – the amount of beam that is reflected. The influence of the laser beam geometry is presented by Θ – incidence angle and Φ – the angle between incidence angle and the viewer direction. Additionally the luminance of the material is described by the parameter n. Thus the Phong model can be described by the following equation (GREGORY, LANDER 2009):

$$I = I_i(k_d \cos^{\Theta} + s_s \cos^{n\Phi}) \tag{4}$$

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.

It is important to notice that at the current stage, this model do not include the effects of atmospheric attenuation and material extinction. Figure 1 depicts the example shape of reflection modeled by Phong in polar coordinates. The angular coordinate depicts the incidence angle while the distance from the 0 point depicts the intensity value.

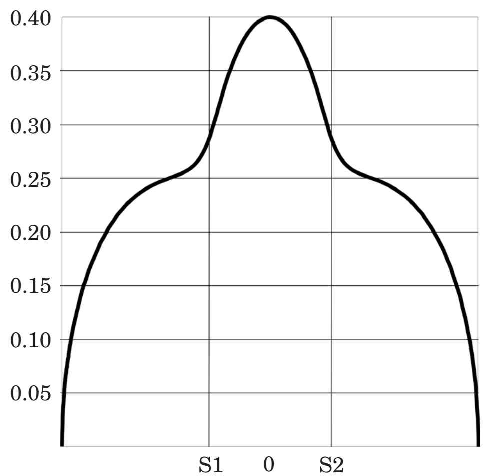

Fig. 1. Intensity plot

Experimental verification of phong model

As mentioned in the introduction, practical verification of this model in real survey environment would be difficult. Therefore verification of the Phong model was performed in the laboratory environment. The tasks connected with laboratory tests were focused in three main problems:
- testing device design,
- materials used for model verification,
- data recording.

Testing devices design was composed of:
- Atmega328 micro controller,
- laser light source,
- photo detector,

– servomotor with target holder,
– PC computer for data storage and visualization.

The main idea was to detect the change of voltage on the photo detector, which resistance changed according to the intensity of the laser light reflected from the test material. To change the incidence angle, the target holder had ability to rotate. The movement of servomotor, output voltage registration and data transfer to PC was made with Atmega328 micro controller. The appropriate micro controller software was coded by authors (application patent). The outline of the device is depicted in Figure 2.

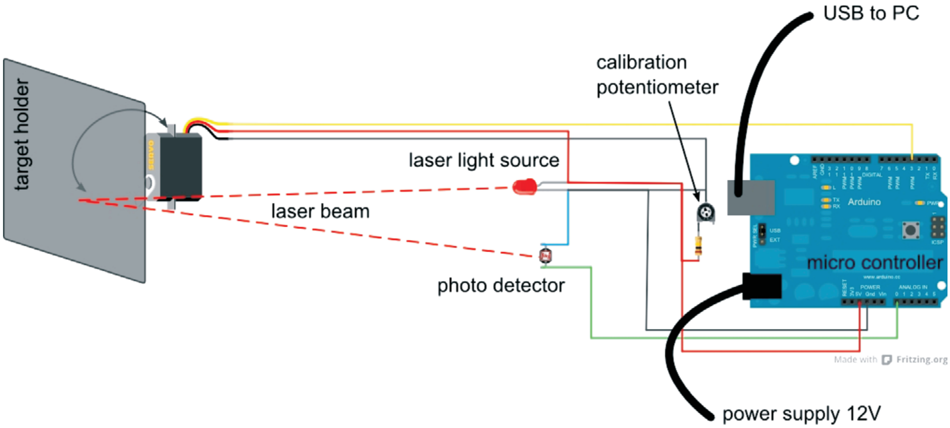

Fig. 2. Design of the testing device (the idea of authors)

The following materials were used for tests: white paper (matte and glossy), gray paper, red paper, blue foil, aluminum, tin foil, sand paper, shiny side of CD.

Results

To fit the parameters of each material to obtained data, a dedicated software in Processing language was developed. The software allowed to fit the data from the model to survey data by modifying three parameters: k_d – the amount of beam that is diffused and k_s – the amount of beam that is reflected and n – luminance. The example of fitting is presented in Figure 3.

In Figures 3a, b, c, d purple lines depicts the surveyed data and black outline is modeled data. The above figures confirms the possibility to use a Phong model for reflector less surveys. Figure 3a presents white, shiny paper. The "spike" at the incidence angle of about 0 degrees is visible. In Figure 3b white matte paper is shown. It confirms that matte materials diffuses the light with no specular reflection. In the case of aluminum (Fig. 3c) there is a lot of specular reflection while almost none diffuse reflection. In Figure 3d, sand paper with gradation of 150 was used. The "outliers" are caused by single sand gains that reflected the laser beam.

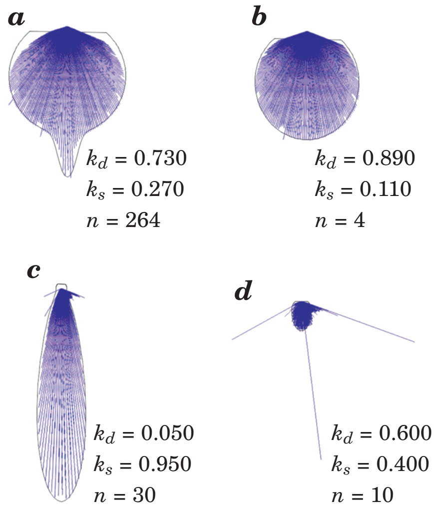

Fig. 3. Purple lines depicts the surveyed data and black outline is modeled data: *a* – white, shiny paper, *b* – white matte paper, *c* – case of aluminum, *d* – sand paper with gradation of 150

Table 1 presents the values of k_d, k_s and n for various materials.

Table 1

Value of coefficients k_d, k_s and n

Material	Value of coefficients		
	k_d	k_s	n
Tin foil	0	1	34
CD	0.02	0.98	130
Aluminum	0.05	0.95	30
Blue duct tape	0.1	0.9	40
Red slightly shiny paper	0.49	0.51	50
Gray paper slightly matte	0.5	0.5	10
White shiny paper	0.73	0.27	264
Blue sand paper	0.87	0.13	6
Red sand paper	0.88	0.12	82
White matte paper	0.89	0.11	4

The values presented in Table 1 varies according to the type of material. Coefficient k-d varies from 0 for tin foil (glossy reflection) to 0.89 for white matte paper (almost diffuse reflection). The coefficient n is smallest for matte white paper (the reflection is blur Fig. 3c) while for white shiny paper it is 264 which means that the reflection is very sharp (it is confirmed in Fig. 3a).

Conclusions

The approach presented above confirms that Phong model can be used to model the intensity and maximum range. In addition the model parameters for some materials were experimentally measured. Obtained results confirms the theoretical basis described in (RAPINSKI, KOWALCZYK 2011). Designed test device works well and can be used to determine Phong model parameters for various materials. The Phong model with obtained parameters can be used for example to unify the intensity parameter while scanning the cylindrical objects (make the intensity independent from the incidence angle).

Translated by JACEK RAPIŃSKI

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