THE MODELLING OF A REFLECTORLESS RANGE FINDER MAXIMUM RANGE WITH PHONG MODEL

Jacek Rapinski

Institute of Geodesy
University of Warmia and Mazury in Olsztyn
jacek.rapinski@uwm.edu.pl,

Kamil Kowalczyk

Chair of Land Surveying and Geomatics
University of Warmia and Mazury in Olsztyn
kamil.kowalczyk@uwm.edu.pl

ABSTRACT

This paper gives a proposition of a model of the maximum range of a range finder. It is based on the laser range equation and a Phong model. It shows how the incidence angle affects the maximum range when measuring to the surface that characterizes with diffuse – specular refection. The results shows that one can determine the boundary angle for which the optimum performance of maximum range is maintained.

1. INTRODUCTION

Reflector-less survey become a common technique in geodetic practice. The main advantage of this method is the possibility to perform a survey without target marking. This feature can be used when measuring over the obstacle like water reservoirs, unaccessible points on hills or slopes, areas restricted for entrance. The examples of the use of reflector-less surveys can be found in [Kowalczyk and Kuczynska, 2009, Kowalczyk, 2011, Suchocki and Wasilewski, 2009].

The major disadvantage of this method is its maximum range. This parameter is strongly dependent on the targets material, lightning, size of the laser footprint. The description of this issues can be found in [Sabatini and Richardson, 2010]. In this paper we have focused on the influence of the incidence angle on the maximum range of the range-finder. According to the laser range equation [Sabatini and Richardson, 2010] the maximum range depends among others on the power of returned signal. In this paper we try to model the maximum range with regard to the incidence angle with use of the Phong model derived from computer 3d graphics [Gregory and Lander, 2009].

2. SIGNAL REFLECTION AND THE MAXIMUM RANGE

2.1 Laser range equation

The maximum range depends on the proportion derived from the laser range equation [Sabatini and Richardson, 2010]:

$$P_R = \frac{\sigma D^4 \tau_{atm} \tau_{sys} P_T}{16 R^4 \lambda^2 K_a^2} \qquad \textbf{(1)}$$

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.

The equation 1 for the totally reflected beam becomes [Kruapech and Widjaja, 2010]:

$$P_R = \frac{\rho D^2 \tau_{atm} \tau_{sys} P_T}{8 R^2} \qquad \textbf{(2)}$$

where ρ stands for the target reflectance.
Deriving R from the equation 2 gives:

$$R = \sqrt{\frac{P_T \rho D^2 \tau_{atm} \tau_{sys}}{8 P_R}} \qquad \textbf{(3)}$$

In the equation 3 D^2, τ_{sys} and the proportion P_T/P_R are constant for a certain instrument. For class I lasers the proportion P_T/P_R is about 4_10^{-4} and for class II laser it is about 3 _ 10^{-7}. The term τ_{atm} depends on the atmospheric extinction coefficient, and is constant for the atmospheric parameters during the survey.

2.2 Types of reflection

One must distinguish three types of reflection:

specular reflection,
diffuse reflection,
retro reflection.

In specular reflection the entire beam is reflected and reflection angle equals incidence angle. In diffuse reflection the beam is diffused according to the Lambert's cosine law [Smith et al., 1968]. Retro reflection occurs when the reflected beam returns the same way that the incidence beam [Friedman and Miller, 2004]. In reflector-less surveys the range-finder's beam usually reflects and diffuses simultaneously (Figure 1).

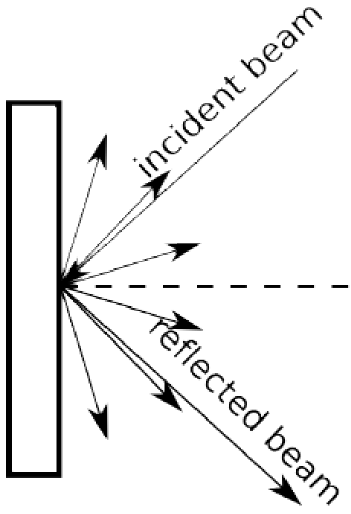


Fig. 1. Glossy – diffuse reflection.

3. PHONG MODEL

The Phong model can be used to model the glossy - diffuse reflection. It's orign is in the computer 3D graphics. It is used to model the reflection of the light from the object. It assumes that the reflected intensity of light can be described by the equation 4.

$$I = I_i \left| k_d \cos \Theta + s_s \cos^n \Phi \right| \quad (4)$$

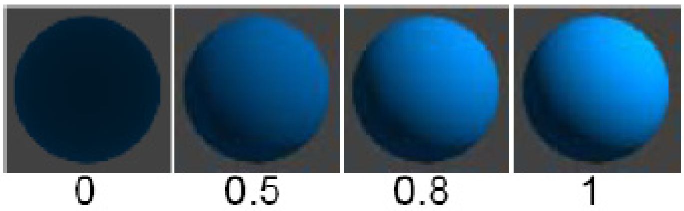
Where:
I – the intensity of the reflected beam,
I_i – the intensity of the incidence beam,
k_d – the amount of beam that is diffused,
k_s – the amount of beam that is reflected,
Θ - incidence angle,
Φ - the angle between incidence angle and the viewer direction,
n- parameter describing the luminance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

Parameters k_d, k_s and n describes the material type, color and a structure of the surface. This is depicted on figures 2(a), 2(b) and 2(c). These parameters can be used to model almost any kind of surface. For the example parameters k_d = 0:4, k_s = 0:6, n = 12 and the incidence perpendicular to the surface, the shape of the intensity plot is shown on figure 3.

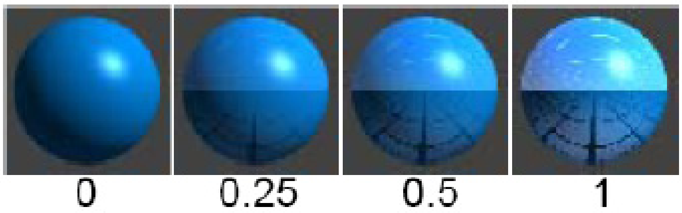
The figure 3(a) shows that there is a range of angle for which the intensity of reflected signal grow rapidly. To determine the boundary angle the inflection of this function must be derived. To do so the second derivative must be calculated.

$$\frac{\partial I}{\partial \Phi} = -k_s n \cos(\Phi)^{n-1} \sin(\Phi) \quad (5)$$

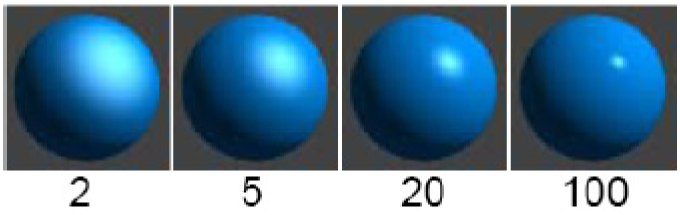
$$\frac{\partial^2 I}{\partial \Phi^2} = -k_s (n-1) n \cos(\Phi)^{n-2} \sin(\Phi)^2 - k_s n \cos(\Phi)^n \quad (6)$$



(a) The influence of the amount of beam that is diffused

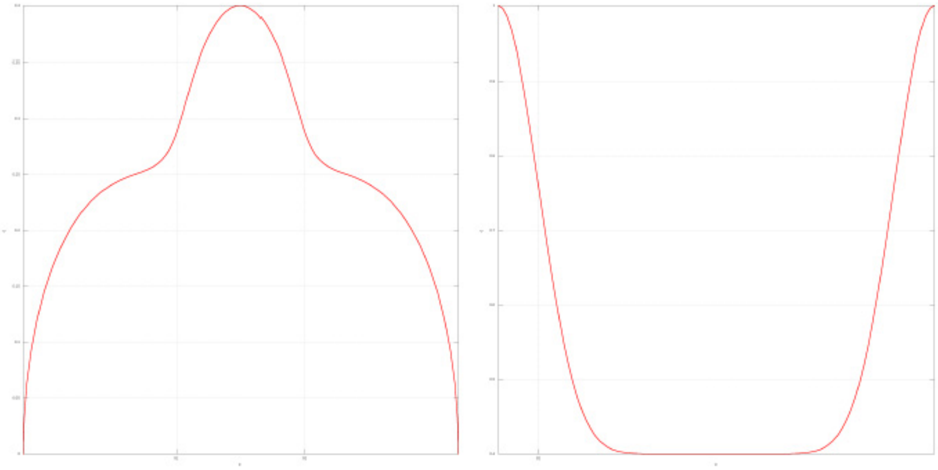


(b) The influence of the amount of beam that is reflected



(c) The influence of the luminance parameter

Fig. 2. MaterIal type, color and a structure of the surface.



(a) Polar (b) Planar

Fig. 3. Intensity plots.

The inflection is in the point where the second derivative is equal to 0. Calculations for the above example:

$$\frac{\partial^2 I}{\partial \Phi^2} = \frac{396\cos(\Phi)^{10}\sin(\Phi)^2 - 36\cos(\Phi)^{12}}{5} \qquad (7)$$

$$\frac{\partial^2 I}{\partial \Phi^2} = 0 \Leftrightarrow \Phi = a\tan\frac{1}{\sqrt{11}} \approx 0.2928[rad] = 18.64[grad] \quad \textbf{(8)}$$

The result of equation 8 means that for the optimal performance of laser maximum range, the incidence angle should be smaller then 18:64grad (of course for the certain material used in this calculation). If we exceed this angle, the maximum range will be decreased.

4 . THE INFLUENCE OF INTENSITY VARIATION ON THE MAXIMUM RANGE

In the equation 3 the reflectance ρ is a fraction of light reflected by the target. This fraction can also be derived from the Phong model:

$$\frac{I}{I_i} = \left[k_d \cos\Theta + k_s \cos^n \Phi\right] \quad \textbf{(9)}$$

Since the influence of the atmospheric extinction is taken into consideration in equation 3 we can rewrite the above equation as:

$$\frac{I}{I_i} = \left[(1-k_s)\cos\Theta + k_s \cos^n \Phi\right] \quad \textbf{(10)}$$

Naming the right side of the equation 10 as the range variation coefficient:

$$\int = \left[(1-k_s)\cos\Theta + k_s \cos^n \Phi\right] \quad \textbf{(11)}$$

Substituting equations 11 into 3:

$$R = \sqrt{\frac{P_T D^2 \tau_{atm} \tau_{sys} \int}{8 P_R}} \quad \textbf{(12)}$$

Figure 4 depicts the influence of the range variation coefficient on maximum range of the laser. The red line presents the above model, while green line presents standard, diffuse reflection.

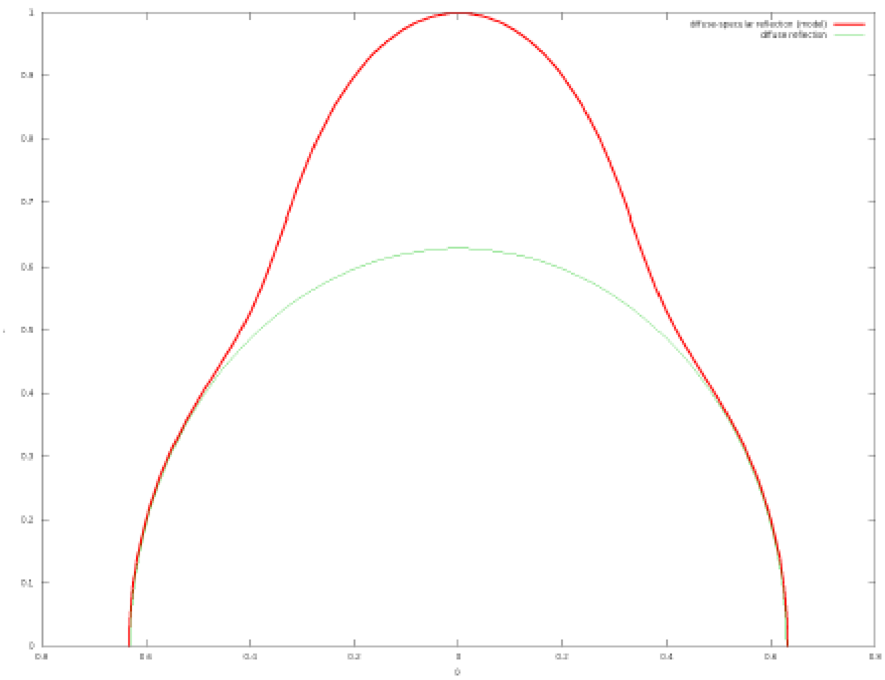


Fig. 4. Range variation coefficient.

5. CONCLUSIONS

This paper presents the proposition of the modeling method of the maximum range of a reflector-less range finders. It uses laser range equation and a Phong model. It shows that for the certain angles of incidence and some materials, the range can enhance by 37% (when the incidence angle is 0^o). This information can be useful when measuring to a distant target. For example the design of control network can be improved if one knows the maximum range of a range-finder.

REFERENCES

E. Friedman and J. L. Miller. Photonics rules of thumb: optics, electro-optics, fiber optics, and lasers. McGraw-Hill Professional, 2004.

J. Gregory and J. Lander. Game Engine Architecture. A K Peters, Ltd., 2009.

K. Kowalczyk. The assessment of the influence of material type on the accuracy of handheld laser range-finder (in polish). Przegląd Geodezyjny, 5, 2011.

K. Kowalczyk and J. Kuczynska. Application of mirrorless total stations for precision architectural objects documentation. Reports on Geodesy, 2(87): 177{185, 2009.

Sahapong Kruapech and Joewono Widjaja. Laser range finder using Gaussian beam range equation. Optics Laser Technology, 42(5):749{ 754, 2010. ISSN 00303992. doi: 10.1016/j.optlastec.2009.11.020.

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

A. R. Smith, F. Jones, and R. P. Chasmar. The detection and measurement of infra-red radiation. Clarendon Press, 1968.

C. Suchocki and A. Wasilewski. Monitoring of shore cliff with the application of scanning instrument. Reports on Geodesy, 2(87):373{380, 2009.