Effects of Target Reflectivity on the Reflected Laser Pulse for Range Estimation

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Abstract— The development of laser ranging technology benefits remote sensing, machine vision and three-dimensional (3D) imaging. Accuracy of these systems strongly relies on the characteristics of laser and detector response. In this paper, reflected laser pulse profile is investigated and analysed based on different target reflectivity. Results show that reflected laser pulse appears to deviate from ideal Gaussian model that is commonly assumed. The reflected laser pulse demonstrates asymmetric Gaussian-shape temporal associates with a time delay. It is observed that target reflectivity that is influenced by the material types and roughness has direct impact to the sensitivity of detection and intensity variations but does not change the distribution characteristic. These show direct connection to deviation in range estimation and should be further evaluated for correction to improve the accuracy in range gated system.

1. INTRODUCTION

Improvement in laser ranging technology is motivated by the need for better performance from various applications. Due to the non-destructive nature, high speed and long range capability offered by laser, it has been deployed across wide range of applications such as remote sensing, machine vision, target detection and tracking, 3D imaging, etc. [1, 2]. Recent development in laser, detector and computer technology further encourage the growth of laser ranging where the system cost becomes more affordable.

Reflected laser pulse returns to incoming direction after strikes on target surface serves as the key information to determine the detection model for Laser Detection and Ranging (LADAR) system. The importance of laser pulse profile and intensity has been emphasized in literature [3–5]. System parameters and conditions such as laser and receiver models, target reflectivity and atmospheric effects could be analysed based on the laser profile, which is useful for result interpretation and prediction. Gaussian model has been the most common assumption used because of its simplicity. [6] suggested that Gaussian is reference of quality for laser source which needs to be extended to define its distribution. Tan et al. proposed that T-location-scale model is more accurate for reflected laser pulse profile [7].

Variations in laser intensity and redistribution of laser pulse energy can be investigated via the reflected laser pulse profile. The characteristics of the reflection is impacted by various factors such as laser source, receiver, target and atmospheric scintillation [8, 9]. Different target surface material and condition causes different measure of effectiveness to reflect energy [10], which possibly creates different response due to receiver deficiencies [11, 12]. Target reflectivity could affect the system accuracy but they are not well controlled in the laser ranging applications. Therefore, this study collects and analyses the experimental data to investigate the effects of target reflectivity on the reflected laser pulse and range estimation accordingly.

2. EXPERIMENTAL SETUP

Our investigation is based on mono-static pulsed system where laser pulse is emitted and received on the same optical axis. The reflecting target has flat surface area much bigger than the illuminated laser beam and is perpendicular to the propagation of the laser beam. With the simplified surface characteristics, the target reflectance ρ is assumed to be uniform and the effectiveness to reflect transmitted laser depends on the target properties such as material type and roughness. Reflected laser pulse P_r with respect to two-way Time-of-Flight (TOF) t is function of target reflectance

ρ, receiver efficiency parameter S, atmospheric attenuation η_{atm}, transmitted laser pulse P_t, and receiver impulse response H [13]. c is the speed of light.

$$P_r(t) = \rho S(r)\eta_{atm}(2r)P_t\left(t - \frac{2r}{c}\right) * H(t) \tag{1}$$

Temporal profile of the reflected laser pulse $P_r(t)$ can be seen as a convolution of the transmitted laser pulse $P_t(t)$ and receiver impulse response function $H(t)$ where the intensity is influenced by range, atmospheric attenuation, target reflectivity, and receiver parameters. In practice, $P_t(t)$ and $H(t)$ are difficult to be determined separately but the convolution results in the system temporal waveform which is the reflected laser pulse that can be captured and analysed experimentally [14].

Our study focuses on the target reflectivity without changing the laser source and detector parameters. We use Q-switched Nd : YAG laser that operates at wavelength of 532 nm with pulse energy 3 µJ and pulse duration 0.5 ns at full width half maximum (FWHM). Silicon high speed biased photodetector with active diameter of 400 µm is setup to capture the laser pulses which transforms the optical signal into electrical signal for diagnosis. Photodetector output and laser sync out signal as reference to indicate laser emission are connected to oscilloscope with 1 GHz bandwidth. Time difference between laser sync out and the captured laser pulse is equivalent to the travel distance given by TOF principle. Figure 1 illustrates the experimental setup to capture laser pulses in the emitting and reflecting direction. Analysis of the reflected laser pulse includes various target surface materials and roughness which are different in term of reflectivity.

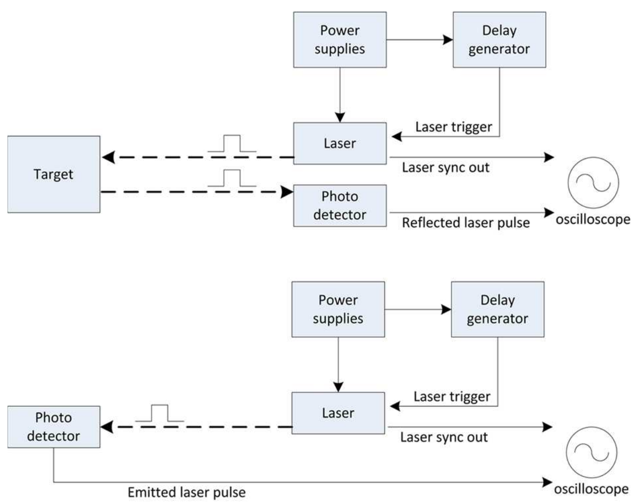


Figure 1: Experimental setup to capture laser pulse in the reflecting and emitting direction respectively to investigate the effects of target reflectivity.

Table 1: Maximum intensity, skewness, and kurtosis analysed for different target surface materials and roughness at 0.6 m.

Target surface	Maximum intensity (V)	Skewness	Kurtosis
Aluminium	0.2251	2.53	8.21
Stainless steel	0.1973	2.55	8.50
Very smooth wood	0.0964	2.56	8.43
Smooth wood	0.0479	2.62	8.91
Rough wood	0.0327	2.60	8.84
White paper	0.0349	2.60	8.83
White crepe paper	0.0341	2.58	8.75
White rough plastic	0.0323	2.59	8.55

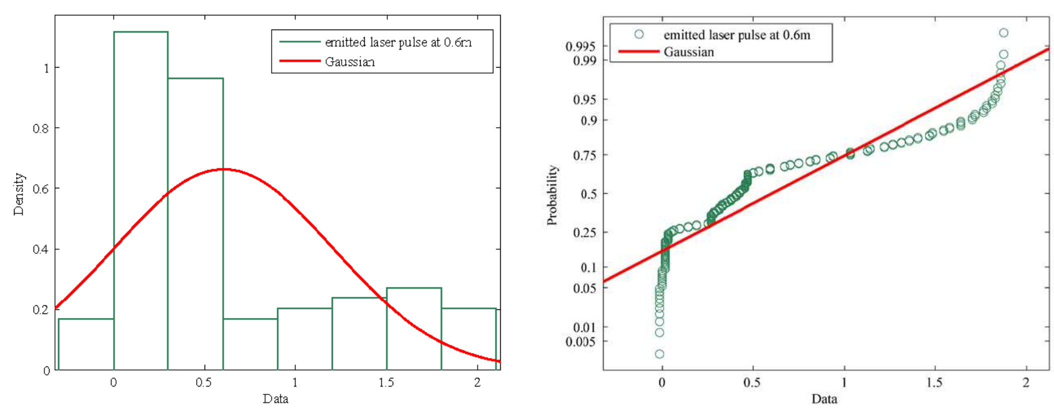
3. RESULT AND DISCUSSION

3.1. Reflected Laser Pulse Analysis

Selected target surfaces have different reflectivity or emissivity, and the analysed result is summarised in Table 1. Statistical analysis based on the measure of skewness and kurtosis is applied. The data shown are based on average of 20 measurements collected at 0.6 m range. Variations in intensity are observed for different target surface materials and roughness. However, distribution characteristics do not seem to vary where no significant difference can be observed from skewness and kurtosis.

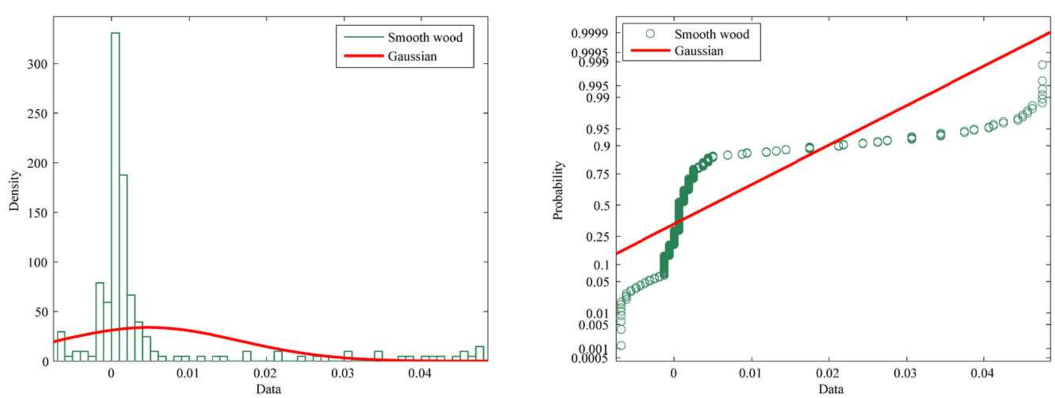
Figure 2 is distribution fitting example of probability density function (PDF) and probability plot (PP) for emitted laser pulse where the data is appropriately fitted with Gaussian model. On the other hand, reflected laser pulse data for all selected target surfaces are deviate from Gaussian distribution where data skewed to the right and have higher probability for extreme values. As an example, distribution fitting for smooth wood is shown in Figure 3.

The laser pulse received is normally assumed in Gaussian form [15]. However, the characteristics of the Gaussian-shaped laser pulse can be affected by multiple factors such as target, receiver, range, and atmospheric effects. Figure 4 shows the temporal signals waveform recorded from our experiment. The emitted laser pulse that is originally a Gaussian temporal is reflected as an asymmetric Gaussian-shape pulse. The asymmetry of the pulse can be examined based on R and



(a) (b)

Figure 2: Distribution fitting of PDF and PP for laser pulse captured at 0.6 m in the emitting direction fits closely to Gaussian model. (a) PDF fitting for laser pulse captured at 0.6 m in the emitting direction. (b) Probability fitting for laser pulse captured at 0.6 m in the emitting direction.



(a) (b)

Figure 3: Distribution fitting of PDF and PP for reflected laser pulse of a smooth wood target surface at 0.6 m shows deviation from Gaussian model. (a) PDF fitting for smooth wood target surface at 0.6 m. (b) Probability fitting for smooth wood target surface at 0.6 m.

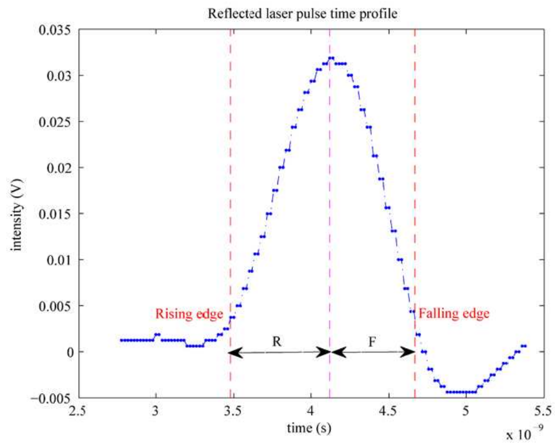


Figure 4: Reflected laser pulse is observed as asymmetric Gaussian-shape temporal.

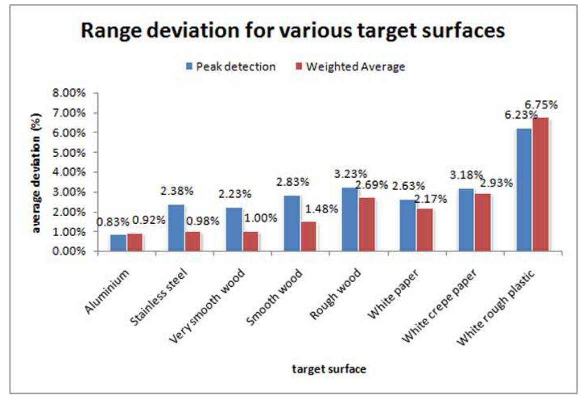


Figure 5: Average range deviation based on peak detection and Weighted Average range estimation. Deviation is higher for rough or weak reflective target surface as compared to smooth or strong reflective target surface in general.

F, which are the horizontal width from the vertical line containing the peak maximum to the rising and falling edges measured at 10% of the peak height.

3.2. Deviation on Range Estimation

Reflected laser pulse $P_r(t)$ is convolution of transmitted laser pulse $P_t(t)$ and receiver impulse response $H(t)$. For our analysis, target reflectivity and receiver response are considered as the influencing factors. We have observed the reflected laser pulse as an asymmetric Gaussian-shape temporal associates with time delay which possibly causes deviation in range estimation. The average range deviation based on peak detection and Weighted Average method can be seen in Figure 5. In general, the range deviation is higher for rough or weak reflective target surface as compared to smooth or strong reflective target surface. Time delay t_d causes the TOF detected from reflected laser pulse t_r is always greater than the actual two-way TOF $t = \frac{2r}{c}$. Further work is continued to compensate t_d attributed by the asymmetric pulse caused by different target reflectivity and receiver response accordingly.

$$t_r = t + t_d \tag{2}$$

4. CONCLUSION

This study has investigated the effects of target reflectivity and receiver response to reflected laser pulse. The emitted laser pulse that is originally Gaussian distributed deviates after reflected off a target surface. Besides, the temporal analysis shows that asymmetric Gaussian-shape pulse is reflected. These characteristics are consistent for all tested targets which are different in term of material types and roughness.

Laser pulse reflected off target surface shows significant drop in intensity and time delay caused by target reflection and receiver response which contributes to deviation in range estimation. From our observation, rough or weak reflective target surface exhibits higher deviation as compared to smooth or strong reflective target surface. To accomplish accurate range sensing, this effect of target reflectivity should be considered and compensated in the range estimation which will be continued in future work.

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