Applicability of Random-Modulation CW Technique on LED Mini-Lidar for Mars Rover

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Abstract: A compact LED lidar was constructed and field-tested with the aim to observe the Mars' dust devils. It was constructed to fit a 10 cm-cube dimension limit. In its present form, it has a 0.75W (7.5nJ/10ns) pulse power, and 500 kHz pulse repetition frequency. These parameters were optimized so rapid measurement of dust flow in the near range is feasible. Although, it is limited to nigttime measurement, the pseudo random modulated continuous wave (RM-CW) technique will increase its signal-to-noise ratio (SNR) and realize a breakthrough in daytime measurement. The PRBS-8 code length with 8ns pulse width parameters were shown to meet the requirements for the LED lidar.

Key Words: LED lidar, RM-CW, Mars Rover

1. Introduction

An LED mini lidar system was constructed to fit a Mars rover with the purpose of measuring quantitatively the "dust devils" on Mars surface[1)]. Although the motion and size of the observed Martian dust devils can be estimated from images obtained from satellites and rovers, still the quantitative information from these estimates were poorly constrained[2)]. Hence, in situ measurements of near-ground atmospheric and dust activities on Mars will be useful in the study of this phenomenon.

Given the size limitation of a Mars rover, and the extreme surface temperature condition on Mars, our team have examined the use of LED (light emitting diode) as the light source of the mini lidar system to be installed in a Mars rover. Aside from being energy efficient, heat sink independent, and tough against circumference change, previous researches on LED lidar have proved that the LED lidar can be used in near-ground Earth atmosphere monitoring[1,3-7)]. The beam radiation angle is wide compared to its laser counterpart, but this wide beam divergence of the transmitter will establish a constant overlap in the near-field with the receiver's narrow field of view (F.O.V.). Hence, the system design has initially been focused on the robustness against tough treatment, transportability (10 cm-cube limit), and capability for near-range monitoring (~30 m) of dust activities.

2. Setup

To date, there are two compact LED lidars that were fabricated given a 10 cm-cube limit: version 1, and version 2 (see Fig. 1). Version 2 was the improved version of version 1, specifically, in terms of compactness, design, and stability. Their specifications are provided in Table 1. A high pulse repetition frequency was set to improve the SNR due to the low pulse energy (7.5nJ/10ns). To be able to follow the high repetition frequency (500 kHz) of the transmitter, the photon counter was fabricated using a high-speed FPGA (Spartan 6, Xilinx) with a time resolution as low as 1 ns or 0.15 m distance resolution equivalent. In addition, the high-speed photon counter has the feature to generate the pseudo random modulated sequence (PRBS) with linear feedback shift register (LFSR) of 8 to 15-bit length (L-bits). The PRBS is the most commonly used RM code underlying the RM-CW lidar, which was first demonstrated by Takeuchi, et al.[8,9)] in a Mie scattering lidar. In addition, RM-CW technique is one technique that can recover a weak signal buried from a random noise, thus, can be utilized to further increase the SNR of the current LED lidar system. The power consumption of the current photon counter is 2 W for 1 channel DAQ, but it was verified that it can still be reduced to 1 W.

Table 1 Parameters of the transmitter and the receiver.

Transmitter		Cassegrain Receiver	
Light Source	NUV-LED NCSU034B (Nichia Corp.)	Barrel	5 cm
Wavelength	385 nm	F.O.V.	3 mrad
Pulse Width	10 ns	Primary Mirror Aperture	10 cmϕ
Pulsed Power	0.75 W	Primary Mirror Focal Length	72.25 mm
Pulse-Repetition Frequency	500 kHz	Secondary Mirror Diameter	2.5 cmϕ
Beam Divergence	70 mrad	Secondary Mirror Focal Length	-25 mm
Beam Size	3 cmϕ		

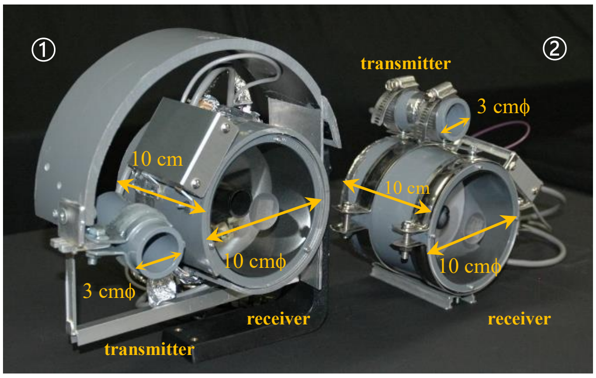

Fig. 1 Two versions of the compact LED lidar for near-range ground experiment: ① version 1, and ② version 2.

3. System Performance of the 10 cm-cube LED Lidar

In the wind tunnel experiment that was conducted in Japan Meteorological Agency in Tsukuba, the LED lidar was able to monitor the smoke's flow, diffusion and convection from a glycerine smoke generator. A time-distance smoke profiles are presented in Fig. 2. The smoke generator was positioned 16 m away from the LED lidar, and directed towards it. It can be seen in Fig. 2-1-A that there is a strong backscattered echo from about 15 m and gradually decreased over time, then registered a slight increase after 40s at about 2-3 m in front of the lidar system. Given this information, we can deduce that the smoke underwent diffusion and convection processes, as illustrated in Fig. 2-2-A. Similar scenario is presented Fig. 2-1-B with a different wind speed, 0.5 m/s. Due to a faster wind speed, it cuts down the convection process to a shorter period.

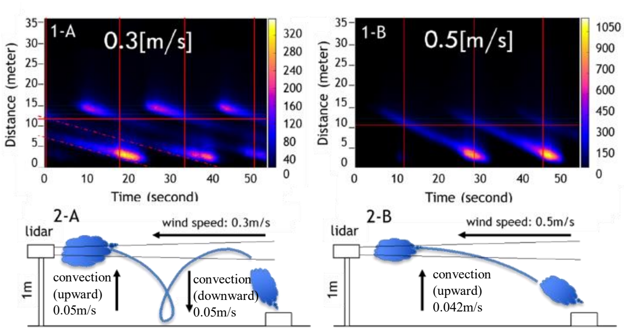

Fig. 2 Smoke profiles in two perspectives: (1) height vs time graph and (2) possible smoke convections, given two different wind speeds: (A) 0.3m/s and (B) 0.5m/s, at fixed smoke interval, 20s.

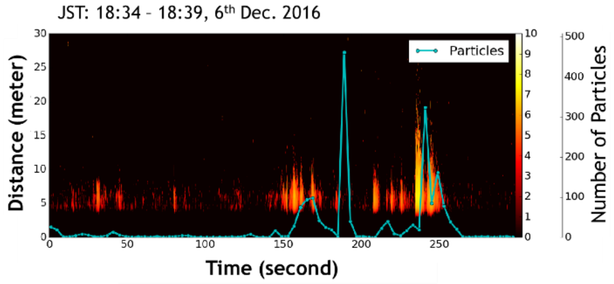

Fig. 3 Dust profile from both LED lidar ver. 2 data and dust counter data (Inage-Kaigan, Chiba, Japan).

In the field-test experiment in Inage-Kaigan, Chiba, we monitored the dust particles near the ground surface. The wind condition was about 6 m/s northward, which was directed downwind with respect to the lidar system. To be able to monitor in such condition, the LED lidar was placed a few tens centimeters above the ground with an elevation angle close to the horizontal. Figure 3 shows a good correlation between the lidar data and the dust counter data. There was no detected dust farther than 20 m. It is an indication that the dust might have already settled to the ground right away.

In the current LED lidar setting, it can only monitor during nighttime. A limitation due to its low pulse peak power giving it a low SNR. One possible solution to this is to install the RM-CW technique in the current LED lidar.

4. RMCW

For a RM-CW lidar, the typical source of the binary sequence is the shift register of L-bit length. The length (2^L-1) of these PRBS-L (i.e. PRBS-1, PRBS-2, etc.), defines how long the modulated signal will be before it cycles again. In our current setup, the LED is set to transmit a pulse width of 10ns with a pulse repetition frequency of 500kHz. These parameters where chosen to be able to rapidly observe dust particles in the near-range. To be able to modulate the PRBS in our LED transmitter circuit and still have the same repetition frequency as before, several factors were considered: (1) PRBS length, and (2) circuit tolerance and limitation. A section of the generated PRBS-8 waveform of length 255 bits is presented in Fig. 4. This just shows the capability of the high-speed photon counter to generate an 8ns (Δt) minimum pulse width necessary to reproduce the 500kHz pulse repetition frequency (in PRBS it is equivalent to 1 cycle iteration). Its derivation is illustrated in Fig. 5. Upon verification that we can implement the necessary random modulated code, we proceeded with the transmitter circuit improvement to be able to accommodate the random modulated code, which shifted the scheme from peak power transmission to average power transmission.

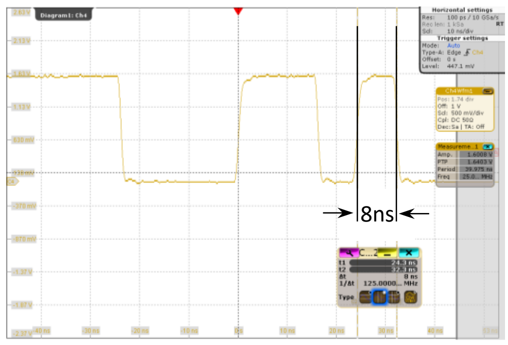

Fig. 4 A section of the PRBS-8 generated waveform with 8 ns minimum width generated using the PRBS generator feature of the high-speed photon counter.

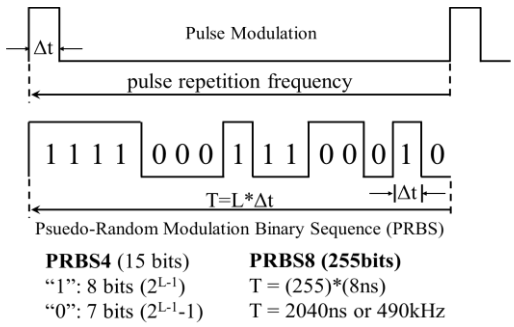

Fig. 5 Illustration of a pseudo-random modulated signal of length 15 bits (PRBS-4) leveled to a pulse modulation for visual length comparison. A sample computation of one cycle iteration (period, T) of a 255 bit (PRBS-8) code length is also shown.

5. Summary

Two compact LED lidars were fabricated to fit the required 10 cm-cube dimension limit for the Mars rover. They were both tested and both have shown promising results in near-range dust echo measurement. Although, the measurement is still restricted to nighttime, the possibility of utilizing the random modulated CW technique was shown to be theoretically possible for the requirement of the LED lidar. This could potentially increase the SNR of the LED lidar. Currently, we are improving the transmitter circuit to accommodate the random modulated code.

References

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