DESIGN AND DEMONSTRATION OF A MINIATURE LIDAR SYSTEM FOR ROVER APPLICATIONS

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Abstract

A basic small and portable lidar system for rover applications has been designed. It uses a 20 Hz Nd:YAG pulsed laser, a 4-inch diameter telescope receiver, a custom-built power distribution unit (PDU), and a custom-built 532 nm photomultiplier tube (PMT) to measure the lidar signal. The receiving optics have been designed, but not constructed yet. LabVIEW and MATLAB programs have also been written to control the system, acquire data, and analyze data. The proposed system design, along with some measurements, is described. Future work to be completed is also discussed.

Background

Laser-based atmospheric remote-sensing instruments continue to be essential to many NASA missions. Applications include coherent Doppler velocimetry, altimetry, ranging, flash LIDAR imaging, mapping of wind patterns, and measurements of atmospheric constituents by Differential Absorption Lidar (DIAL). In particular, the Mars Instrument Development Program (MIDP) develops ground based miniature instruments that are space-qualifiable and ready for response to Mars mission Announcements of Opportunity (AO) [1]. Rovers and applications that utilize them have also grown in popularity recently and this research will focus on developing a compact lidar system to be used on a ground based rover for the detection of aerosols and cloud distributions.

Lidar is a remote-sensing technology that measures the properties of scattered light with respect to the distance or range of a target. Lidar systems are based upon the same principles that are used in radar and sonar systems. A radar system uses radio waves for detection and ranging, but a lidar system has the distinct advantage of using light for detection and ranging. Lidar is much better for certain applications because very small particles, such as aerosols, can be easily detected due to the fact that a lidar uses much shorter wavelengths in the electromagnetic spectrum. Radar systems use radio waves that may not detect small particles because the wavelength of radio waves is too large for accurate detection of small particles [2].

The operation of a lidar system is fairly simple. A light pulse is transmitted into the atmosphere and that light is scattered in all directions by various molecules and particles in the atmosphere. Some of the scattered light is reflected back to the lidar system, where it is focused by a telescope into a photodetector. The photodetector usually is connected to a data acquisition system and a computer that can measure the amount of backscattered light as a function of distance. From that description, it is clear that any basic lidar system will require four main components: a laser, a telescope assembly, a photodetector (APD or PMT), and a computer system for data acquisition [3].

Proposed Research and Significant Progress

A block diagram of the proposed miniature lidar receiver subsystem for the rover system design is shown in Figure 1.

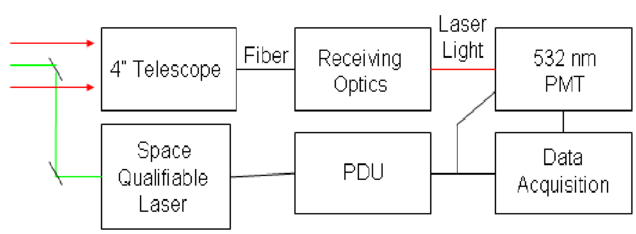

Figure 1 – Miniature Lidar Rover System Design

This block diagram consists of six main components: the laser, the telescope assembly, the receiving optics (including components such as mirrors, filters, etc.), the photomultiplier tube (PMT), the power distribution unit (PDU), and the data acquisition system. Part of the research for the lidar components has already been completed, and the components that are currently being used are discussed below.

Compact lidar systems can be designed using many different approaches, and this particular system will utilize a laser with a low laser repetition rate and a high energy per pulse (mJ per pulse). Although this type of laser is not eye-safe nor able to be deployed unattended, it can rapidly collect data with a very good signal to noise ratio [4].The laser that is currently being used is the ULTRA CFR Nd:YAG Laser System made by Big Sky Laser Technologies. The laser that will be used in future work is the Fibertek space-qualifiable laser (a laser driver was recently fabricated for this laser), which is capable of outputting wavelengths of 1064 nm, 532 nm, and 355 nm. The proposed research interest is the 532 nm laser line, which will be detected by a PMT. The other two laser lines (355 nm and 1064 nm) will be dumped. The telescope that is currently being used is the Meade ETX-105AT Astro Telescope. It has a 4-inch diameter receiving area, so it is small enough for a compact design.

The PMT that is being used to measure the 532 nm return signal was based on a circuit designed by Don Silbert (GFSC) and modified by Terry Mack (Lockheed Martin). This design supports the Hamamatsu R7400 & R7600 metal package photomultiplier series tubes. By using a small telescope as a receiver, the lidar return signal will be very weak, so we need an extremely sensitive PMT with low noise and high gain. This makes the Hamamatsu PMTs an ideal choice for detectors since they have low noise, high gain, and excellent response times, making them perfect for any light detection application. The PMT requires voltages of 15 V and +/- 5 V for power, and it receives the power signals from the power distribution unit

The power distribution unit (PDU) is the most vital part of not only the lidar system, but the entire rover system. Without proper power, the components will either not work or could possibly be damaged. The PDU receives power from a 24 V DC battery and distributes it appropriately to the data acquisition system (NI PXI Chassis), the laser driver module, and the 532 nm PMT. It also routes control signals from the NI PXI Chassis to individual system components. The custom-built PCB board and the case to house it were populated so that jacks and connectors could be used to route signals to the appropriate system components. Recently, the PDU (along with a custom-built laser driver) was used to not only power the Fibertek laser, but to properly fire it as well.

The data acquisition system consists of a NI PXI chassis (NI PXI-1031DC) that uses four cards: a NI PXI-8106 Embedded Controller, a NI PXI-6115 Multifunction I/O card for input and output signals, a NI PXI-6259 Multifunction DAQ card for input and output signals, and a NI PXI-1428 Image Acquisition card for the ICCD camera (for a separate Raman spectrometry application to be used on the rover). The data acquisition system runs from a LabVIEW program that controls input/output signals, control signals, power signals, and steering on the rover. A simple LabVIEW program was written for the PMT, so that it acquires the PMT's output signal, but the program is just a sub-program and is a tiny part of the overall program that is used to control the rover and its subsystems. The LabVIEW program simply acquires the signal from the PMT, displays each shot in real time while acquiring the signal, and displays the intensity of the signal with respect to time and distance when signal acquisition is complete. The LabVIEW program will also output the data to a text file so that it can be used in other analysis programs, such as MATLAB.

A MATLAB program was developed for data analysis. This program opens the PMT's acquired data file, graphs and displays the original intensity, and then graphs and displays the background subtracted, range-corrected intensity. The latter of the graphs allows for easier data analysis and is created by taking the original output signal, subtracting the average noise from the signal, and then correcting the signal by multiplying it by the range squared.

The previously developed MATLAB program was modified and used for 532 nm and 1064 nm laser line data analyses. Data for the 1064 nm laser line was acquired and analyzed using the modified program. An example is given below.

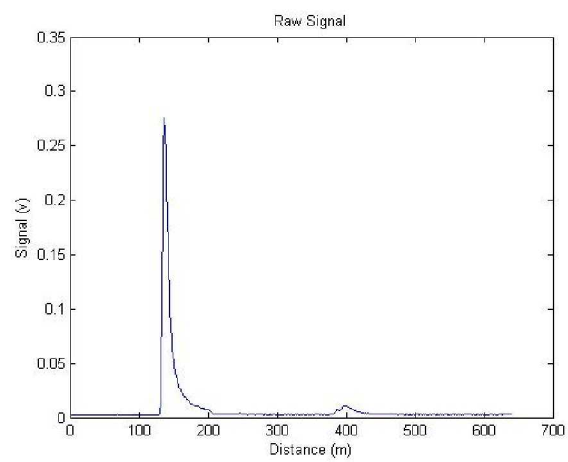

Figure 2 – Raw Signal MATLAB Plot for 1064 nm data

From the raw signal, background subtraction was performed by averaging the background noise that is present initially in the signal. In Figure 2, it would be the average of the voltage values from 0 to 100. Background subtraction is performed for each averaged shot and the intensity is plotted for the background subtracted signal. Finally, the program performs range correction and plots the intensity for the signal. An example of the final output for the 1064 nm laser line data is given below.

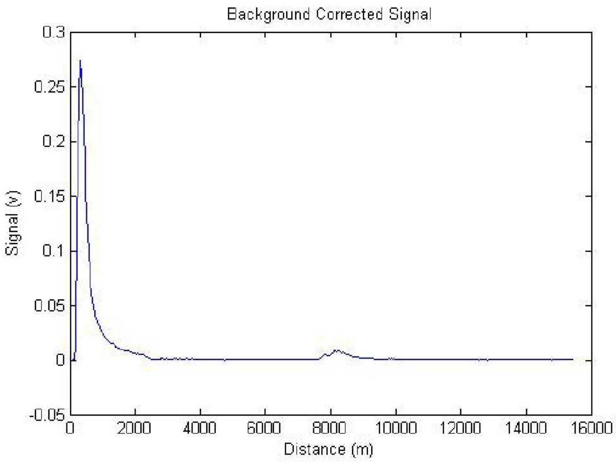

Figure 3 – Background Corrected Signal for 1064 nm data

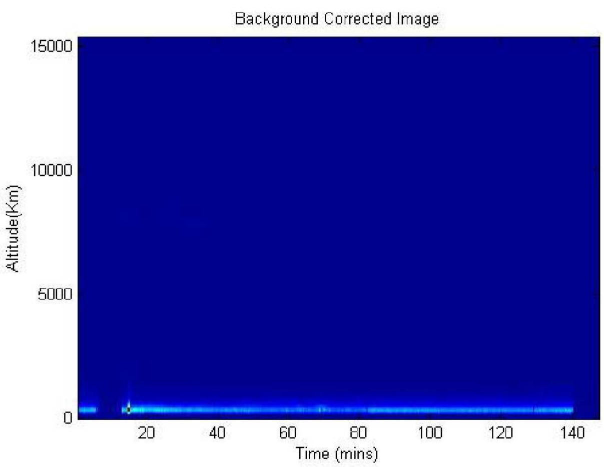

Figure 4 – Background Corrected Relative Intensity Graph for 1064 nm data

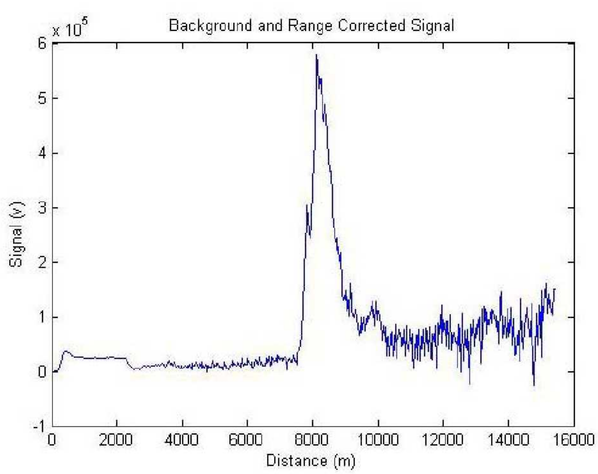

Figure 5 – Background and Range Corrected Signal for 1064 nm data

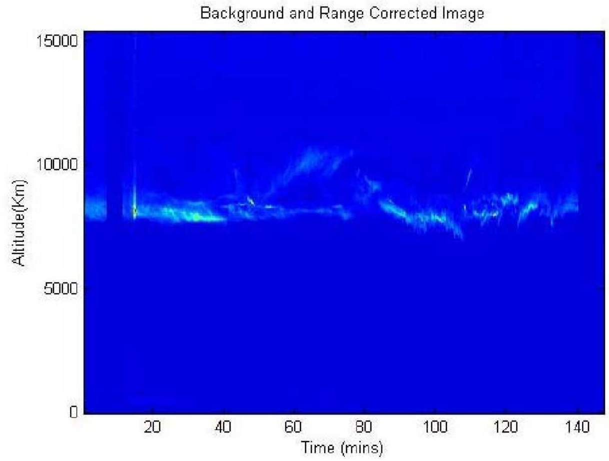

Figure 6 – Background and Range Corrected Relative Intensity Graph for 1064 nm data

The results in the four figures above show that there was a cloud around 8000 m at the time the data was taken. Although the data used was for 1064 nm, slight modifications in the program will easily allow analysis of 532 nm data from the proposed PMT.

In February 2010, the basic experiment shown in Figure 7 below was setup to test the capability of the 532 nm PMT.

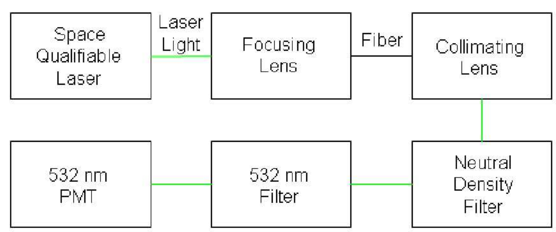

Figure 7 – PMT Experimental Setup

The ULTRA CFR Nd:YAG laser was used for the experiment, and it can produce up to 45 mJ of energy at 532 nm. The laser was not used at full energy, but it still produced a large enough amount that it could burn the PMT, so a neutral density filter was used to reduce the energy being input to the PMT. The focusing lens was used to focus the laser light into an 800 meter long fiber and a collimating lens was used to collimate the light on the other end of the fiber. The 532 nm filter was used so that the PMT was only receiving the 532 nm laser line.

The data acquisition system was triggered by the laser, and the LabVIEW program created specifically for PMT measurements was used to measure the laser light. An optical power meter was used to measure the light right before the PMT and the power was found to be approximately 40 nW. After performing a few measurements, the gain of the PMT was adjusted to 1000 so that the output signal that was being read by the data acquisition system was 1 V. The results of the final measurement are given below.

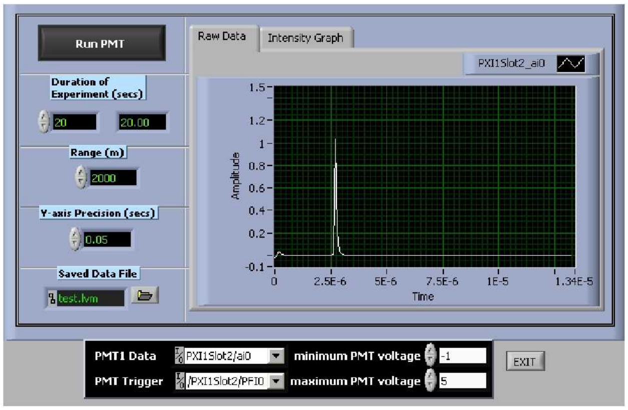

Figure 8 – Raw 532 nm Lidar Signal

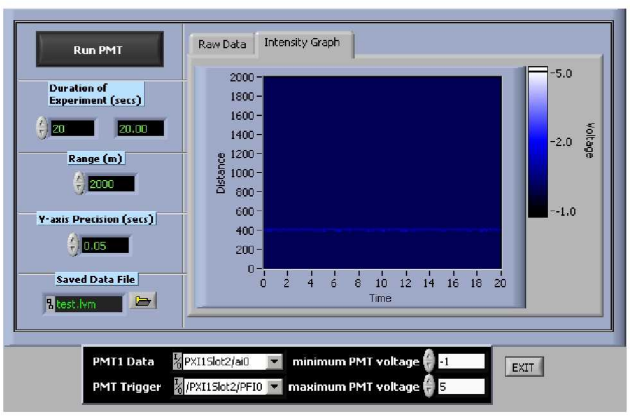

Figure 9 – Relative Intensity for 532 nm Signal

The duration of the experiment was set to be 20 seconds and the maximum range was set to be 2000m for the distance scale of the intensity graph. Figure 8 shows that the PMT received the laser signal about 2.75 μs after it was triggered by the laser. Knowing that the speed of light is 3×10^8 m/s, the calculated length of the fiber is 825 m, which is close to the actual length. Figure 9 shows the relative intensity graph for the received signal. We expect to see a solid line at approximately 800 m, but the line is at approximately 400 m instead. This is because the program is written for a lidar return signal. For a lidar signal, the distance to an object that you are measuring would need to be divided by two since the light will travel to the object at distance d, and then be reflected back and received by the telescope at another distance d. The program accounts for this and divides the distance by two, thus accounting for the disparity in the intensity graph value. The measurements show that the PMT will be accurate for the lidar system, and the signal to noise ratio is excellent, meaning the signal will not be overpowered by noise.

Future Work

Due to large lead times on components, such as the laser driver, PDU, and optical components, much work is still left to be done. The beam-steering mirrors for the laser and the receiving optics were recently designed and ordered. Once they are delivered, the optics will immediately be setup and tested. At the moment, we will dump the 1064 nm and 355 nm laser lines, but another PMT or APD may be added to measure those return signals as well. Other future work will include:

1) Setting up the laser transmitter to transmit the laser beam to the atmosphere and then acquire the atmospheric data by the lidar detection system.
2) Characterizing each optical component suitable for the lidar system. This includes the alignment of the optical components and electronic setup for the lidar measurements.
3) Analyzing the characterization data to achieve the best alignment conditions for the laser and detector with respect to the lidar system requirements.
4) A report summarizing the research findings, alignment of the laser with respect to the detector and associated electronics, and all results will be delivered to NASA Langley.

Conclusion

Great progress has been made concerning the individual components of the portable lidar system. The PMT gave favorable results with an excellent signal to noise ratio. The PDU and laser driver have been fully tested for functionality and operation. The data acquisition system, the LabVIEW program, and the MATLAB program have all worked properly as well. All of the initial results have been great, but future work must still be completed before the system will be complete and fully operational on a rover. The design of a small portable lidar system to be used on a rover for detection of aerosols and clouds is possible and can be used by the MIDP program at NASA Langley. Once the system has been completely assembled and placed onto the rover, field tests will be performed to ensure the design truly works as expected.

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