Experimental Verification of Wind Lidar with Long-Duration Frequency-Modulated Pulse

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Abstract: In our previous research, a new wind lidar which accomplishes high power and high range resolution by transmitting laser pulses with long duration and frequency modulation was proposed. In the proposed wind lidar, analytical performance evaluation under ideal conditions indicated that accuracies of wind ranging and velocimetry increases in proportion to the square root of pulse duration. In this research, we investigated accuracies of modulated pulse shaping that is one of issues to realize the proposed wind lidar. We developed an experimental system which directly returns generated laser pulses to its receiver, and digitally measured the returned waveform. Although, in the returned signal, the returned waveform is distorted compared to its ideal waveform, the result of matched filter processing showed sufficient performances that the mainlobe width was almost maintained, and peak power was reduced very little by −0.3 dB as compared with the ideal waveform.

Keywords: Coherent Laser Radar, Doppler, Frequency Modulation.

1. Introduction

In recent years, demand for wind lidars has increased greatly because of their technological progress and lowered price. Through wind lidars are used for various practical purposes, wind lidars with higher output and higher resolution have been desired. So far, researches and developments have made much efforts for high power output by improving the performance of laser sources and optical amplifiers.

As a new approach of a wind lidar for higher power and higher resolution, a wind lidar transmitting laser pulses with long duration and frequency modulation was proposed. A method that achieves high power and high resolution by transmitting long duration pulse and applying modulation and demodulation techniques has been utilized in radar. In lidar, however, large Doppler shifts due to very high carrier frequencies compared with radar becomes problematic. Since a frequency of the received signal is largely shifted, a correlation between a reference signal (which is normally a replica of the transmitting signal) and the received signal is lost. Therefore, it is impossible for lidars to apply pulse compression by matched filter as for radars. The proposed approach prepares multiple reference signals which are frequency-shifted corresponding to pre-supposed relative velocities, and matched filter processing is performed with each of them. Results of matched filter processing derive a range-velocity profile of received signal. According to analytical performance evaluation under ideal conditions, accuracies of wind ranging and velocimetry increase in proportion to the square root of pulse duration while maintaining the range resolution [1].

For demonstrating the proposed wind lidar, several issues have to be solved. One of issues is accuracy of pulse shaping. In the proposed wind lidar, since chirp-like frequency modulations derives large errors in velocimetry (because of characteristics in its ambiguity function [2],) a random phase modulation is used. Although waveform of phase modulations has discontinuous changes, the discontinuous waveform cannot be shaped accurately due to response times of optical instruments. In this research, we
studied accuracy of waveform shaping, that is, actual waveforms were obtained by an experimental model, and signal processing performances given by the actual waveform were examined.

2. Experimental Model

In order to verify accuracy of waveform shaping, we developed an experimental model that directly detect modulated signal. Figure 1 shows the optical setup of the experimental model. In the experimental model, a laser source with wavelength of 1550 nm is used, and the optical signals modulated by Acousto-optic Modulator (AOM) is directly returned to a detector. The laser transmitted from the laser source is divided via the coupler, one is to the AOM and the other is to heterodyne detection. The modulation signal generated by arbitrary waveform generator (AWG) is input to AOM, and the laser after AOM is modulated. In future observation, modulated signals will be emitted to free space and scattered signals form aerosol will be received. In this experiment, however, they are not released to free space but are directly returned to its receiver. The returned signal is converted to an intermediate frequency by the heterodyne detection. Table 1 shows the parameters of the signal used in this experiment. The carrier frequency and the intermediate frequency are 194 THz (1550 nm), 80 MHz, and a pulse length is 10 µsec.

![Figure 1. Experimental setup](image)

Table 1. Parameter of signal in experiment

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carrier frequency</td>
<td>194 THz (1550 nm)</td>
</tr>
<tr>
<td>Intermediate frequency</td>
<td>80 MHz</td>
</tr>
<tr>
<td>Modulation</td>
<td>8-PSK</td>
</tr>
<tr>
<td>Bandwidth</td>
<td>2 MHz</td>
</tr>
<tr>
<td>Pulse duration</td>
<td>10 µsec</td>
</tr>
</tbody>
</table>

3. Results

In Figure 2, an experimental waveform (right) and a corresponding ideal waveform (left) are compared. Major disagreements between the two are seen at times switching phases. The experimental waveform indicates that the time required for a phase switch is about 0.12 µsec. Meanwhile, in specifications of the AOM, its rise time is 0.1 µsec, which means that the waveform distortion is mainly caused by the AOM’s rise time.

Figure 3 shows spectra of the ideal waveform (left) and the experimental waveform (right). Sidelobes are lower in the experimental waveform than the ideal waveform. Looking at the experimental waveform again (Figure 2), the experimental waveform is shaped as multiplying a window function to the ideal
waveform. Thereby, it is speculated that the reduction of sidelobes is caused by a windowing due to the system’s response time.

Figure 4 shows range-velocity profiles which are resulted from the matched filter processing, whose left and right plots are ones calculated from the ideal and the experimental waveform, respectively. Since the experimental model directly returns the transmitting signal, it can be considered as its received signal is from a single particle at zero meter in distance and zero meter per second in velocity. Comparison of the two plots showed that the mainlobe width was almost maintained, and peak power was reduced by –0.3 dB.

Figure 2. Ideal waveform (left) and experimental waveform (right)

Figure 3. Spectrum of ideal waveform (left) and experimental waveform (right)

Figure 4. Range-velocity profile of ideal waveform (left) and experimental waveform (right)
4. Conclusion

In this research, we experimentally verified accuracies of the waveform shaping which is one of issues for realizing our proposed wind lidar transmitting laser pulses with long duration and frequency modulation. In the proposed method, since phase modulation is used, there are discontinuous points in the waveform of the modulated signal. And, discontinuous waveform cannot be accurately generated due to a response time of the optical instruments. In order to verify the accuracy of pulse shaping, an experimental model which directly returns generated laser pulses to its receiver was developed. As a result of experiments carried out, the returned waveform was distorted around the discontinuous points compared with the ideal waveform. The distortion almost corresponded to a rise time of its optical device (AOM). By comparing range-velocity profiles resulted from the returned and the ideal waveforms, moreover, it is confirmed that the mainlobe width was almost maintained, and peak power was reduced by –0.3 dB. Therefore, it is concluded that the influence of pulse shaping is negligible for realizing the proposed wind lidar.

In the future, we will demonstrate the proposed wind lidar by further development of the experimental model to emit lasers in free space and observe scattered waves.

5. References
