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# Re-Normalization Method of Doppler Lidar Signal for Error Reduction

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## 1. Introduction

A Doppler lidar [1-4] has been developed to provide wind measurements with high spatial and temporal resolution [5,6], and the use of Doppler lidar technology to measure atmospheric winds has gained importance in atmospheric dynamics and weather forecasting based on numerical models [7].

According to the Doppler effect, velocities are derived from the transmission changes of backscattered light through a frequency discriminator [8].

Many researchers in the field of a Doppler lidar system use a molecular or atomic absorption discriminator (such as an iodine cell), which is used to calculate the amount of Doppler frequency shift and lock the frequency of the transmitter [9]. The use and precise control of such equipment make a laser of a lidar system stable. However, there could be a fluctuation in the Doppler signal at a pulse-to-pulse or long-term region no matter how the equipment is used. The unstability of the laser temperature control and a frequency locking algorithm, environmental noises, and unknown effects make the laser frequency unstable.

In this study, we propose a calibration method that can reduce the fluctuation of Doppler signals in a Doppler lidar system by using a reference signal from an additional laser beam path which is separated from the laser beam used for frequency locking process and located at an iodine cell. The reference signal is monitored and acquired by the lidar system controller. We apply incoherent Doppler wavelength discrimination to the Doppler lidar receiving system and evaluate the system's performance using a rotating disc.

## 2. Experimental setup for Doppler lidar system

A schematic diagram of the configured Doppler lidar system is shown in figure 1. We divide the injection-seeded Nd:YAG laser beam into two separate beams using a beam splitter (B.S1). The transmitted beam is sent to a rotating metallic plate, whereas the reflected beam is transmitted to a frequency locking system through an optical fiber. The transmitted laser lights are scattered from the rotating disc with an adjusted rotating speed. The speed of the rotating disc can be determined from the Doppler receiving system and an improvised encoder. The Doppler-shifted scattered light is collected in the backward direction and transmitted through the optical fiber. Subsequently, the light is divided into two channels. One (reference) channel detects the scattered light directly, whereas the other channel detects the transmitted light that passes through an iodine cell.

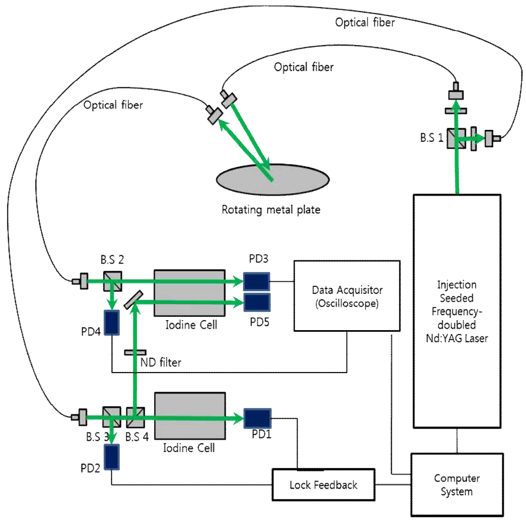
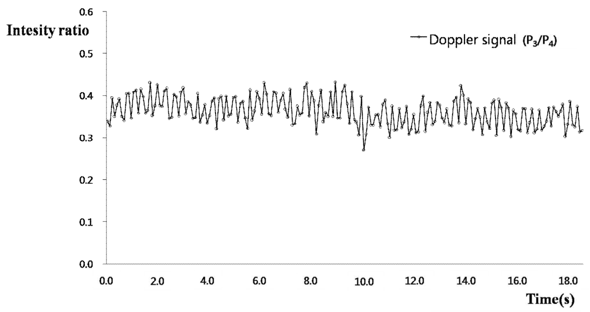


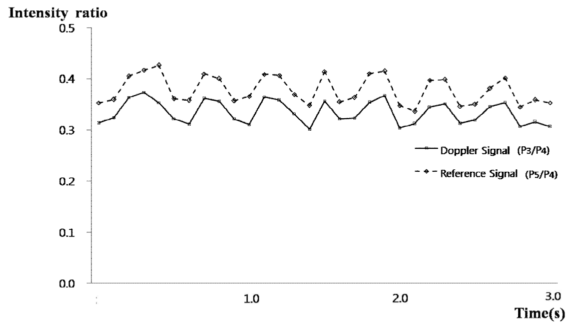

Figure 1. Schematic diagram of the configured Doppler lidar system.

For frequency locking equipment, we divide the laser light reflected on beam splitter 1 using beam splitter 3 before it is transmitted through the target iodine cell. The reflected light signal is acquired by photo diode 2, and this signal is used to compensate the pulse·energy fluctuation of the seeded laser. The transmitted light is divided using beam splitter 4. One path is used for monitoring the frequency shift by PD1, and the other path is used for calibrating the Doppler signals by PD5. When the laser frequency modulating voltages are impressed from -1V to 1V, the reflected laser beam intensity (PD2) is not varied but the transmitted laser beam intensity (PD1) is varied with laser frequencies on account of iodine gas' absorption feature. Therefore the ratio variation of PD1 signal to PD2 signal shows the relative frequency shift of the laser. The ratio was locked to 0.5 by using the lock feedback equipment as shown in figure 1(b). If the laser lights scattered from the rotating disc have Doppler frequency shifts, the ratio of PD3 signal to PD4 signal will be varied with the velocity of the rotating disc. As this ratio (Doppler signal) can be unstable owing to various noises the reflected laser beam from B.S4 was used for re-normalization. The signals of PD3, PD4 and PD5 were acquired by oscilloscope. These ratios were displayed at monitor and computer system saved the acquired data.

### 3. Experimental results




(a)




(b)

Figure 2. Raw Doppler signal (a), raw Doppler signal and reference signal in pulse to pulse (short term fluctuation).

The rotating plate stopped by about 8 seconds and accelerated for a few seconds. After then, the rotating plate was maintained at the same velocity. We acquired the signal of PD3 and PD4 for 18 seconds. As shown in figure 2 (a), the fluctuation of the Doppler signal was so big in entire rotating conditions that we could not even discriminate the rotating state of the plate, i.e. we could not see whether the plate was moving or not. Figure 2 (b) shows the Doppler signal (SD) and reference signal (SR) for re-normalization by 3 seconds. The fluctuation of the Doppler signal has a similar periodic shape with the reference signal excluding their absolute ratio. We therefore used this similarity for re-normalizing a Doppler signal.

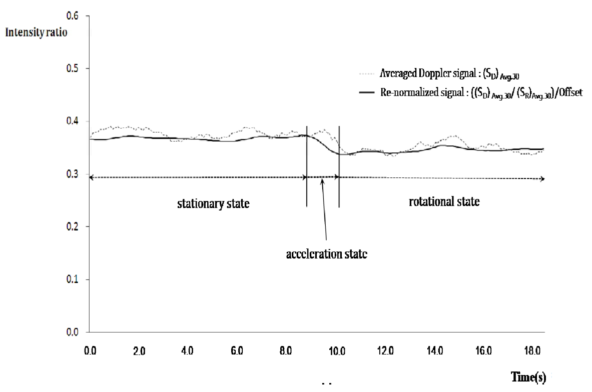



Figure 3. Re-normalized Doppler signal to use the ratio of Doppler signal and reference signal

In order to reduce the fluctuations of raw signals, we filtered both signals of raw Doppler signal and reference signal. All measurements were averaged by 30 pulses for 18 seconds and we used a reference signal ratio from photo diodes 4 and 5 as a re-normalization factor. As shown in figure 3, the fluctuations in the re-normalized signal were much smaller than those of the raw Doppler signal for the entire area.

### 4. Conclusions

In this paper, we presented a re-normalization method for the fluctuations of Doppler signals from the various noises mainly due to the frequency locking error for a Doppler lidar system. For the Doppler lidar system, we used an injection-seeded pulsed Nd:YAG laser as the transmitter and an iodine filter as the Doppler frequency discriminator. For the Doppler frequency shift measurement, the transmission ratio using the injection-seeded laser is locked to stabilize the frequency. If the frequency locking system is not perfect, the Doppler signal has some error due to the frequency locking error. The re-normalization process of the Doppler signals was performed to reduce this error using an additional laser beam to an Iodine cell. We confirmed that the re-normalized Doppler signal shows the stable experimental data much more than that of the averaged Doppler signal using our calibration method, the reduced standard deviation was $4.838 \times 10^{-3}$.

### 5. References

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