# Laser Doppler vibrometer for real-time speech-signal acquirement

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Received November 10, 2008

Laser Doppler vibrometer (LDV) has a potential application prospect in remote sensing. Based on the correlation theories of heterodyne detection, a LDV system with a configuration of all fiber and heterodyne techniques is developed to detect the sound signal through the vibration of glass. Experimental results show that the LDV system has an ability to acquire the real-time speech signal 25 m away through glass. While, the system signal-to-noise ratio (SNR) value decreases with the increase of the glass thickness and the detection distance.

*OCIS codes:* 280.3340, 060.2840, 070.1170.
*doi: 10.3788/COL20090708.0732.*

Laser Doppler vibrometer (LDV) is a kind of measurement to detect the speed of the target's vibration based on Doppler frequency shift in a remote and non-contact way. With high spatial resolution and wide dynamic range, LDV has a wide application in industry and military[1−3]. Homodyne and heterodyne detection techniques are normally implemented in LDV[4,5]. The homodyne detection system has a more complicated optical path than the heterodyne detection system. In addition, it does not possess the ability of time-domain wave reconstruction. On the contrary, the heterodyne detection is a preferable technique for high sensitivity and signal-to-noise ratio (SNR) value. In this letter, a LDV system using a fiber laser and other fiber components for the heterodyne coherent detection is developed, and it is used to detect the real-time speech signals through glass. A few experiments are implemented with different distances and thickness of glass.

Figure 1 shows the principle block diagram of the LDV we developed. The LDV is composed of transceiver unit and signal processing unit. A single frequency fiber laser with the linewidth of 6 kHz at wavelength of 1550 nm is used as the transmitter. The output light is divided into two beams by a fiber splitter. Transmitted light is frequency-shifted of 55 MHz by an acousto-optical modulation (AOM), and the residual light is taken as the reference laser beam (LO). The modulated beam is transmitted to glass perpendicularly through an optical circulator and a telescope. Then, the reflected beam with Doppler shift due to the vibration of glass is received by the same telescope, and it is mixed with LO by a fiber coupler. Finally, the beat signal is detected by a fiber coupled InGaAs PIN detector.

Demodulation circuits are important modules of the signal processing unit. In the demodulator circuit module I, the high-pass filtered output voltage signal of the PIN detector is the intermediate frequency (IF) input of the quadrature demodulator RF2713 and the double frequency of the heterodyne frequency shift of 55 MHz[6] which drives the AOM is the local oscillator input of RF2713. The detector output signal $V_{\mathrm{out}}(t)$ is given as

$$V_{\mathrm{out}}(t) = k\cos\left[2\pi\left(f_0 + \frac{2v(t)}{\lambda}\right)t\right], \quad (1)$$

where $k$, $f_0$, $v(t)$, and $\lambda$ are the conversion efficiency constant of the optical detection, the heterodyne frequency shift of 55 MHz, the surface velocity, and the optical wavelength, respectively.

Using RF2713 for I/Q quadrature demodulating and passing the low-pass filters[7], the in-phase (I) and the quadrature (Q) output signals can be obtained. Moreover, the demodulator circuit module II is necessary for the purpose of real-time display. The I/Q signals are differentiated and then multiplied cross with each other as illustrated Fig. 1. In the end, the audio signal is constructed by the sum of the two signals, and can be played with the sound card and speaker. Hence, the output analog audio signal corresponding to the reliable and real-time speech signals $U_{\mathrm{out}}(t)$ can be described as

$$U_{\mathrm{out}}(t) = \frac{\pi k^2}{16\lambda}v(t) = \frac{\pi k^2}{16\lambda}\cdot\frac{\lambda\omega(t)}{4\pi} = \frac{k^2}{64}\omega(t), \quad (2)$$

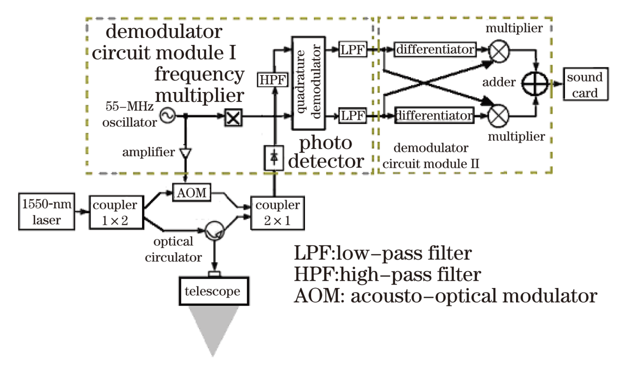


Fig. 1. Principle block diagram of laser doppler vibrometer.

 

where $\omega(t)$ is the glass vibration frequency.

The feasibility of using LDV to detect the speech signals is demonstrated with the setup shown in Fig. 2. As the incident sound wave broadcasting, the glass vibrates and the vibration frequency equals to that produced by the sound-field pressure. The LDV transmitted the beam perpendicularly to the surface of the vibrating glass so as to gain the optimum reflected signal with maximum information.

In order to indicate the capability of the acquirement of speech signals, we set the signals ranging from 400 Hz to 3 kHz with consistent sound intensity while the glass with thickness of 2 mm and the distance of 5 m far away from the LDV. In view of the frequency spectrum of the LDV output signals shown in Fig. 3, it is obvious that the frequency components in the spectrogram are uniform with the transducer frequencies. The region marked by circles represents the signal intensity at a certain specific time and frequency point. Except for the signal regions, the other regions represent the background noise caused by the free space and LDV system, and the noise is broadband distributed. This noise could be filtered by a pass-band filter in a certain degree. Some frequencies are not distinguished as others that are due to the different physical properties of different glasses. In view of this glass, the response to some frequency points is not significant, such as the points of 1900 and 2800 Hz. Also, some signals are stronger than others in intensity that is because of the glass reverberation characteristic which enhances the intensity of the signals indirectly. The results show that the LDV is an efficient technique to detect sound signal through glass.

After testifying the effectiveness of signals detection in the common used audio distance, we execute the testing experiment of the SNR value of LDV with different thickness and different distances for the purpose of verifying the relationships between the thickness of the glass, the detection distance, and the SNR of LDV. First, we set the transducer frequency and the detected distance to 1 kHz and 2.5 m, respectively. Under this condition, we measured the SNR of LDV for different thickness glass, such as 2, 4, 5, and 8 mm. Figure 4(a) shows the relationship between the SNR of LDV and the thickness of glass. With the increment of the thickness of glass, the vibration degree of the glass decreases under the constant sound pressure, and the SNR of LDV decreases correspondingly.

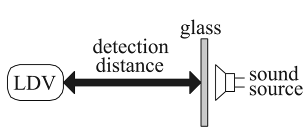


Fig. 2. Experimental setup for detecting speech signal.

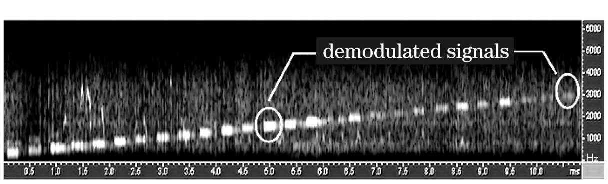


Fig. 3. Frequency spectrum of the demodulate signals with the transmitted signals from 400 Hz to 3 kHz with the same sound level.

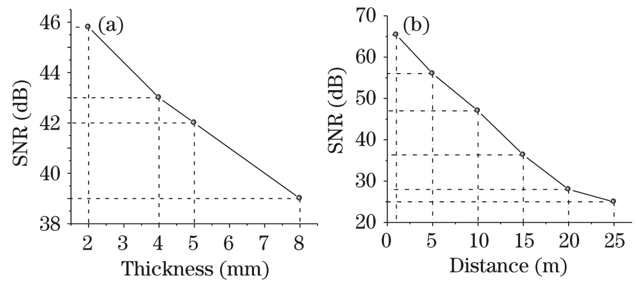


Fig. 4. SNR of LDV versus (a) different thicknesses of the glass with fixed detection distance and sound frequency and (b) different detection distances with fixed glass thickness and sound frequency.

When the glass thickness is 2 mm, the SNR is 45.8 dB. However, SNR decreases down to 39 dB with the glass thickness of 8 mm. The fitting curve indicates that the SNR is exponential decaying as the thickness of the glass increases, which influences the glass vibration velocity and the amplitude directly.

In addition, we changed the distance between LDV and the glass with 1-kHz transmitted signal and fixed glass thickness. As shown in Fig. 4(b), the SNR decreases with the increase of detection distance linearly. When the detection distance is 1 m, the SNR is 65.4 dB. And the SNR decreases to 25 dB while the distance is 25 m. The phase noise caused by free space may be a primary factor impacting the SNR of LDV. In the near future, experiment will be repeated in a silent room to check the effect of environment. According to numerical simulation, the LDV has an ability to detect signal from 40 m away at a minimal SNR of 3 dB. It is notable that the collimation of the laser beam to the glass in the measurement will influence the dropout of the vibration signals.

In summary, a LDV system which is able to detect the real-time speech signals dynamically and conveniently by measuring the remote sound source is demonstrated. The experimental results show that we can obtain good SNR under the condition of thick glass and long detection distance. In the domestic related research field, the detection distance of our LDV system is the furthest. Furthermore, its all fiber structure enables the LDV adjustment simple and flexible. And this LDV will be a potential technology for the communication application in the future.

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