Study on Reproduction of Sound from Old Wax Phonograph Cylinders Using the Laser

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Abstract. Various methods using the laser for reproduction of sound from old wax phonograph cylinders have been developed by the Asakura's group during the past 15 years. Not only the information recorded in the wax cylinders but also the cylinders themselves are a cultural inheritance. Since the developed optical methods are noncontacting and nondestructive, they are powerful tools for repaired or partly broken wax cylinders, and may well be employed in the future for reproducing valuable sounds from old wax cylinders. The principles of the method using the laser are introduced together with their special characteristics and the physical properties of reproduced sounds.

1 Introduction

As well known, Thomas Edison in the United States, a very famous scientist and engineer, invented a recording machine of human voice which was called "Phonograph." After the 10 years' improvement, the phonograph using wax cylinders became very popular. These wax cylinder phonographs were distributed all over the world during about 40 years from 1887 to 1932. In the United States, the wax cylinder phonographs were used mainly for the purpose of amusement. In Europe, on the other hand, these phonographs were used for the various purposes of recording not only the voices of famous people but also the famous music and songs. In addition, these phonographs were used for the academic purpose of recording the various languages of, especially, minority races.

Using the phonograph over the years from 1902 to 1905, B. Pilsudski (1866–1918), a polish anthropologist, recorded the talks and songs of the Ainu people in Sakhalin and Hokkaido on wax cylinders to study their culture. In 1977, Pilsudski's 65 wax cylinders were discovered in Poland and brought to the Research Institute for Electronic Science (RIES), Hokkaido University in 1983 for the purpose of reproduction and investigation of the sounds recorded on them[1].

On the other hand, using the phonograph over the years from 1920 to 1935, Takashi Kitazato (1870–1960), a language professor at Osaka University, recorded the talks and songs of many people in Japan, Taiwan, Philippine, Malaya, Singapore and Indonesia to investigate an origin of the Japanese language. In 1985, Kitazato's 240 wax cylinders were discovered in Kyoto and also brought to the RIES for reproduction of their sounds.

Since the discovery of Pilsudski's and Kitazato's cylinders, many wax cylinders have been brought to the RIES mainly from Europe for the purpose of reproduction of the sounds. The most interesting wax cylinder existing in Europe is of Johannes Brahms (1822-97) whose piano music was recorded.

The stylus of the Edison type phonograph gives a heavy pressure of approximately 20 g to the grooves of the wax cylinder in the reproduction process and, therefore, there is a great risk of damaging the wax cylinder. This is a big problem because not only the sounds recorded on the wax cylinder but also the cylinder itself are part of our cultural inheritance.

Therefore, a reproduction system using a very light pressure stylus was developed in our laboratory. Using the stylus method, we successfully reproduced 60 % sounds from wax cylinders having good conditions. However, there were 40 % more cylinders that had not yet been reproduced. The stylus method cannot be used because the cylinders are cracked or in pieces. These broken wax cylinders were repaired. Figure 1 shows an example for the conditions of the wax cylinder before and after repair. Since the valuable sounds of the talks and songs lost so long ago were recorded on these cylinders, reproduction was most important. To reproduce the sounds from the repaired cylinders, we developed a laser-beam method which is noncontacting and nondestructive[1]. In this paper, we would like to introduce the laser-beam method which is very useful for reproducing sounds from the repaired wax cylinders.

2 Principle of the Laser-beam Reflection Method

Figure 2 shows the principle of a laser-beam method. The laser beam is incident onto the grooves cut on the surface of the wax cylinder and reflected with the angle obeying the reflection law. The reflected beam reaches the detecting plane, placed perpendicularly to the optical axis. The intersection point

(a) (b)

Fig. 1. Wax cylinder (a) in pieces and (b) after repair

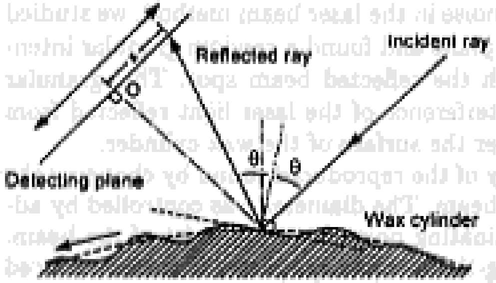

Fig. 2. Schematic 1-D diagram of the laser-beam reflection method

of the reflected beam is separated from the origin by a distance proportional to the reflection angle. When the wax cylinder is rotated, the intersection point moves temporally on the detecting plane. The temporal variation of the intersection position is detected by a position sensitive device (PSD) as a sound signal.

3 Properties and Problems of Reproduced Sounds

The laser-beam method is based on geometrical optics. However, the actual reflection phenomenon from the grooves does not exactly obey the law of geometrical optics because of the finite diameter of the illuminating laser beam. We have found the several problems in the development of this method:

1. Fidelity of the reproduced sound
2. Noise characteristics
3. Existence of echo
4. Occurrence of tracking error

We solved these problems from the quantitative investigation of the reproduced sound signals.

To study the problems of fidelity and noise characteristics, we investigated the long-time frequency spectra of the sound signal produced by using the stylus method and the laser-beam method. In the stylus method, we used the Edison type phonograph. In the laser-beam method, the illuminating spot diameter is 80 µm. As a result, we found that, in the case of the stylus method, the sound is in the frequency range from 250 Hz to 6 kHz. Especially, the resonant frequencies are at 400 Hz, 2 kHz and 4 kHz. In the laser-beam method, the sound intensity with the low resonant at 400 Hz is strong but the sound intensity with the high frequency is weak. The lack of high frequency components makes the consonant indistinct.

The existence of noise inherent in the laser beam method was also examined. The low frequency noise under 300 Hz is very strong. The low frequency noise gives rise to a great deal of degradation on the articulation. On the other hand, the high frequency noise over 1 kHz masks the reproduced sounds and becomes more obstructive to hearing the reproduced sounds.

To investigate the cause of the noise in the laser beam method, we studied the reflected spot at the detecting plane and found a random granular intensity pattern existing together with the reflected beam spot. This granular pattern may be produced from interference of the laser light reflected from the micro-structure distributed over the surface of the wax cylinder.

We also investigated the fidelity of the reproduced sound by changing the diameter of the illuminating laser beam. The diameter was controlled by adjusting the distance z of the illuminating point from the waist of the beam. Figure 3 shows the variation of long-time frequency spectra of the reproduced sounds with the spot diameters. With an increase of the beam diameter, the high frequency components are greatly decreased. This may be due to the smoothing effect for the time-varying directions of beams reflected from the groove within the illuminating beam spot. The lack of high frequency components makes the consonant indistinct. From this investigation, we conclude that the most suitable spot diameter is 30–130 μm from the viewpoint of the fidelity of the reproduced sound.

Figure 3 also shows that the high frequency noise suddenly decreases with an increase of the illuminating beam spot diameter. On the other hand, the low frequency noise exists independently of a variation of the spot diameter. Therefore, the high frequency noise can be effectively suppressed by using the illuminating beam with the large diameter. On the other hand, the noise signals in the low frequency region have a constant intensity independently of the beam diameter. This low frequency noise below 300 Hz may be sup-

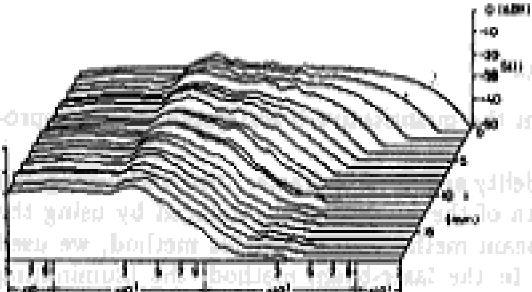

Fig. 3. Long-time frequency spectra obtained from sound signals reproduced by the laser-beam reflection method as a function of the distance z from the beam waist

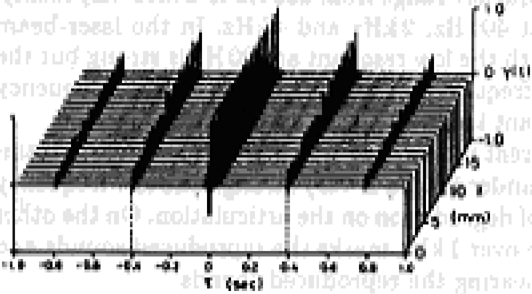

Fig. 4. Autocorrelation functions of reproduced sound signals as a function of the distance z from the beam waist

pressed by using a high-pass filter since the sound information in this region is not originally recorded. From the viewpoint of noise reduction, the noise is suppressed by using the laser beam with the spot diameter over 80 μm.

Another problem is to reduce an echo. The echo is overlapped on the reproduced sounds with an increase of the illuminating beam diameter. Figure 4 shows the autocorrelation functions of time-varying sound signals as a function of the distance z. The maximum peaks at $\tau = 0$ sec results from the sound signals reproduced from the grooves illuminated by the laser beam. The second peaks at $\tau = 0.4$ sec come from the echo and their magnitudes correspond to the intensity. It is seen that the intensity of the echo increases with an increase of the beam diameter.

The laser beam having a larger spot diameter than the width of grooves illuminates the neighborhood of the grooves on both sides and, therefore, the echo is produced together with the main sounds. We found that the intensity of the echo is under 30 % of the main sound intensity for the spot diameter under 100 μm. Under this condition, the existence of the echo does not disturb the hearing of the reproduced sounds.

4 Tracking Error

There is the possibility that the illuminating beam gets out of the grooves, producing the tracking error, because it does not directly trace the grooves of the wax cylinder like in the case of the stylus method. The tracking error results mainly from the position error of the driving part in the reproduction system. As shown in Fig. 5, if the tracking error happens, the incident beam is reflected to the y-direction. In this case, the intensity of the reproduced sounds decreases suddenly because the intersection point of the reflected beam gets out of the one-dimensional PSD.

To avoid the tracking error, we used the two-dimensional (2D) PSD and the lens driver of the compact disk player. The 2D-PSD allows independent detection of the x- and y-coordinates of the beam spot position. The time-varying values of the x- and y-coordinates of the reflected beam become the sound and the tracking error signal, respectively. The tracking error signal is

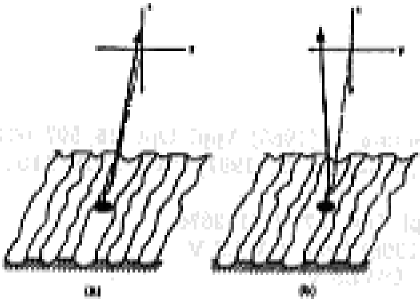

Fig. 5. Optical rays reflected from the grooves (a) without and (b) with the tracking error

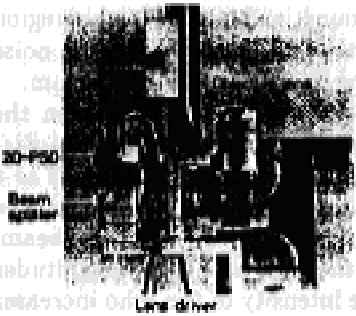

Fig. 6. Optical reproduction system with 2D-PSD and the lens driver to compensate the tracking error

fed to the lens driver to move the lens. By moving the lens, the illuminating spot moves to the center of the groove to keep the normal illumination.

Figure 6 shows the reproduction system with the 2D-PSD and the lens driver. By using this system, we obtained the stable reproduction of the sound with the constant intensity.

5 Further Development of the Method

The laser-beam reflection method introduced above has been developed further to improve its performance and to be applied to various types of old records. To solve the noise problem, an incoherent light source was tried, by which the granular pattern in the beam spot at the detection plane is suppressed. To improve the tracking, modifications of the mechanical part were conducted. A contact method on the basis of light-weight optical fiber was also proposed as an alternate way for improving the tracking[2].

A method using the diffraction property of the laser beam was developed to reproduce sound from old disk records in which the sound is recorded as lateral winding of the sound grooves[3]. More recently, the laser-beam reflection method was applied to negative cylinders which are replicas of wax cylinders[4]. The system for long cylinders are also developed[5].

Finally, it is emphasized that the developed optical methods are basically noncontacting and nondestructive. These methods are powerful tools for various types of old records, and may well be employed in the future for reproducing valuable sounds from them.

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