EFFECT OF REFLECTIVE SURFACE ON THE IMPULSE RESPONSE OF THE SECONDARY PATH OF AN ACTIVE NOISE CONTROL SYSTEM

Sajaad Boodoo and Yasdeo Bissessur,
Department of Electrical & Electronic Engineering, University of Mauritius, Reduit, Mauritius
Email: sboodoo@govmu.org

Roshun Paurobally
Mechanical and Industrial Engineering Department, Qatar University, PO Box 2713, Doha, Qatar

Previous research has shown that a reflective surface has an impact on the control performance of an active noise control system. System identification of the secondary path is of utmost importance in the effectiveness of the control branch of an active noise control system. It is thus essential to accurately model the secondary path with the right number of filter coefficients to have acceptable performance results. In this paper, the effect of a reflective surface on the impulse response of the secondary path of a single channel ANC system is outlined and discussed. Experiments show that the reflective surface indeed has an effect on the impulse response and can affect the performance of the system. The orientation of this reflective surface can be selected in order to optimize the impulse response of the secondary path for best results.

Keywords: Impulse response, system identification, reflective surface.

1. Introduction

Active Noise control is a technique which is based on the principle of superposition, where an artificial sound of same amplitude but opposite in phase as the noise source is combined with the unwanted sound to cancel both sounds [1]. In practical solutions there are many rigid surfaces around an active noise control system such as ground and walls. However, the effects of these reflective surfaces have hardly been taken into account in the analysis such that free field solutions have been assumed mostly [2]. Reflective surfaces affect both the power output and the control performance of an active noise control system [3]. The parameters that effect these changes are amongst others, the distance between the plane and the source, the angle of orientation between the plane and the sources, or the frequency of the primary source. The extent by which these factors affect the control performance of the active noise control system, is dependent on the configuration of the system. For example the effect of a reflecting surface on an active noise control system decreases when the distance between the plane and the active noise control system increases. In general, a reflecting plane, has a positive effect on an active noise control system, but there need to be a study of the overall system to optimize the presence of the reflective body [4].

In an active noise control system, it is also important to have a good model of the secondary path, in order to have a good control performance and stability of the system [5]. However, the effect of
reflecting surfaces and their orientation on the impulse response function and frequency response is still not well understood. In this paper, this effect will be studied and discussed. In section 2, a theoretical background is given in terms of expressions to account for the reflecting surface. Section 3 shows the experimental setups for the different configurations used. Section 4 gives the results and discussions for the different expressions carried out. Finally, in Section 5, the conclusions are given together with the scope for future work.

2. Background Theory

2.1 Effect of a Reflective surface

In free field, the impedance of a point source, $q_a$, is given by [2]

$$\text{Re}\{Z_m\} = \frac{\rho_0 c_0 k^2}{4\pi}$$  \hspace{1cm} (1)

where $\rho_0$ is the air density of sound; $c_0$ is the velocity of sound in air and $k$ is the wave number. The power radiated by the point source, $q_a$, is

$$W_m = \frac{\rho_0 c_0 k^2}{8\pi} q_a^2$$  \hspace{1cm} (2)

In the presence of a reflective surface, the impedance is affected and differs as per the following expression

$$\text{Re}\{Z_1\} = \frac{\rho_0 c_0 k^2}{4\pi} (1 + \frac{\sin kD}{kD})$$  \hspace{1cm} (3)

Where $D/2$ is the distance between the point source and the rigid plane. Likewise, the power dissipated is also affected by the factor $\left(1 + \frac{\sin kD}{kD}\right)$, such that in the presence of a reflective plane [6], the power becomes

$$W_1 = W_m \left(1 + \frac{\sin kD}{kD}\right)$$  \hspace{1cm} (4)

In the presence of a reflective surface, the source impedance and the power are both smaller than in free field, when $kd$ (where $d$ is equal to $D/2$) lies within the range $(2n-1)\pi$, where $n$ is an integer [7]. For two reflective surfaces, as shown in Figure 1, three image sources namely $q_{a1}$, $q_{a2}$, and $q_{a3}$ can be found in the x-y plane and x-z plane, according to the mirror effect. The distances from the point sources and the planes are $d$ and $h$ respectively. The expression for the power becomes

$$W_2 = W_m \left(1 + \frac{\sin kD}{kD} + \frac{\sin kH}{kH} + \frac{\sin k\sqrt{(D^2 + H^2)}}{\sqrt{(D^2 + H^2)}}\right)$$  \hspace{1cm} (5)

where $D=2d$, and $H = 2h$.

![Figure 1. Point source and its images sources in the presence of two rigid planes](image-url)
As the rigid plane is tilted along the vertical axis, the impulse response of the secondary path is affected. Similarly, by selecting the correct angle of orientation, the power output of the system can be reduced and the control performance optimised.

2.2 System identification and impulse response

Figure 2(a) shows the block diagram of the estimation of the secondary path using an adaptive filter. White noise, v(n), is used as the excitation signal. S(z) is the unknown secondary path which is modelled by the adaptive system identification filter S'(z). The secondary path represents the DAC, power amplifier, loudspeaker, microphone, ADC and the acoustics of the room as shown in Figure 2(b). As mentioned, it is very important to have an accurate model of the secondary path as it impacts on the performance and stability of the system. The excitation signal v(n) is used to drive the loudspeaker via a power amplifier. This signal is then captured by the microphone and fed back to the signal processing platform through its ADC input. The error signal e(n) is picked up by the error sensor for use by the LMS to update the filter S(z). The error signal can be written as e(n) = v'(n) – v''(n). The updated adaptive filter can be expressed as

$$S(n+1) = s(n) + \mu v(n) (v'(n) – v''(n))$$

where \(\mu\) is the step size.

In the system, the filter coefficients that will be generated by the system represent the impulse response of the unknown system. Generally, an impulse response can be defined as the time domain response of a system under test to an impulsive stimulus. In acoustics, the impulse response can also be denoted as the acoustical signature of the system. In this context, to have an accurate impulse response, it is desired to have a sufficiently long FIR filter coefficient to be able to represent the system adequately [8]. In the presence of reflective surfaces, it is expected that the reflections will result in a longer impulse response waveform such that a longer FIR coefficient would be desirable. However, a long FIR filter increases the computational complexity of the FxLMS algorithm.

The frequency response is the quantitative measure of the output spectrum of the system in response to a stimulus, and is used to characterize the dynamics of the system. It is a measure of how the magnitude and phase of the output changes as a function of frequency. Relative to the impulse response, the frequency response is the Fourier Transform of its impulse response. In this particular application, for the secondary path model, the frequency response will show any resonance or anti resonances, in its respective frequency range. Here also, this will depend upon the length of the FIR filter coefficients used to model the system. Introduction of a reflective plane, will show any changes
in the frequency response of the system, provided the adequate number of FIR filter coefficients is used.

3. Experimental set up and configuration

Figure 3 shows the experimental setup used in performing the system identification of the system. The development platform is the Professional Audio Development Kit (PADK) which features a low cost TMS C320 6727 DSP [9]. The sampling frequency for the experiments is set at 4 kHz which is adequate for ANC below 500 Hz, for example. The single channel system also includes a power amplifier (QD 4960 interM), a loudspeaker (Pioneer TS-WX 303) and the microphone being used is an electret microphone (with preamplifier Maxim MAX4466). In this experiment, the reflective plane is a melamine board 0.9 m x 1.0 m with a thickness of 6 mm. The melamine board is at a distance of 60 cm from the reference microphone. These distances were selected due to space restrictions.

The model of the secondary path is obtained without the external reflective surface. The impulse response together with its corresponding frequency response is obtained. The system is then tested in the presence of the reflective surface (melamine board), with angles $\alpha$ of $0^0$, $10^0$, and $20^0$, as depicted in Figure 4. Its effect on the impulse response function and frequency response can then be observed. The results are discussed in Section 4.

Figure 3. Experimental set up of rigid plane and system identification

Figure 4. Tilting angle of reflective plane
4. Results and discussions

Figure 5(a) shows the impulse response function of the system without the reflective panel. It shows that there no response until approximately fifteen samples, which represents the overall propagation delay of the system, followed by oscillations after which the system eventually decays to zero. The first peak represents the dominant electro-acoustic response and is the most prominent in the impulse response. There are also successive oscillations which show that the system is reverberant due to surfaces such as the walls. A system with no reverberation (anechoic room) will show no oscillations after the main peak. Figure 5(b) represents the impulse response with the melamine board at an angle of $\alpha = 0^\circ$, and at a distance of 60 cm from the microphone. The response shows multiple significant peaks after the main peak. The additional noticeable peaks after forty-five and fifty-seven samples are due to the effect of the external rigid plane whereby the system experiences multiple reflections. Thus, these reflections arrive later but decays to 0 ultimately. The effect of the panel seems to increase the reverberation time of the system.

In the frequency response in Figure 6(a), the peak at 120 Hz represents the main resonance of the electro-acoustic environment which dominates the frequency response in the low frequency range. Figure 6(b) shows the frequency response of the system with the reflective plane. It shows that there are now two distinct resonances below 500 Hz namely at 120 Hz and 320 Hz, and one at 520 Hz. The resonant frequency at 320 Hz and 520 Hz are now more pronounced in the presence of the melamine board. The resonant frequency at 520 Hz has a much lower amplitude compared to the two main resonant frequencies. Another difference is the overall amplitude of the resonant frequencies between the two configurations. With the rigid plane, the amplitude of the main resonant frequency is slightly higher.
Figure 6 (a) and 7 (b) shows the impulse response and frequency response respectively, for the system with the reflective plane at an angle $\alpha$ of 10°. From figure 5(b) and 7(a), it is seen that the amplitude of the main and the additional peaks, for the reflective plane tilted at 10°, is lesser than that when the rigid plane is at the vertical position ($\alpha = 0^\circ$). However, it is also noticed that the peaks with the surface at $\alpha = 10^\circ$, occur after the same number of samples for the system with the surface at $\alpha = 0^\circ$. The frequency responses shown in figure 6(b) and 7(b) do not illustrate any significant differences. Figure 8(a) and 8(b) shows results for the reflective surface tilted at 20°. Similarly, it is found that for the impulse response functions, the peaks are lesser still in amplitude compared to the surface at $\alpha = 0^\circ$, and $\alpha = 10^\circ$. However, to understand better the effect of the orientation angle of the reflective surface on the impulse response, it will be necessary to test the system with other values of the tilting angle, $\alpha$. 
5. Conclusions and future work

In this paper, results of the impulse response of the secondary path model with and without a reflective panel have been presented. It has been shown that indeed, the reflective panel has an effect on the secondary path whereby the environment becomes more reverberant, and the impulse response shows multiple additional oscillations. The frequency response confirmed the presence of additional resonances caused by the reflective panel. This paper also investigated the effect of different orientation angles of the panel on the impulse response. It is seen that increasing the angle of the reflective surface with the vertical axis, produces peaks with lesser amplitude. However, to be able to analyse the system deeply, it is necessary to study the effect of the orientation angle of the reflective surface, on the performance control of an active noise control system. Future work will also involve the study of the effect of the different length of the impulse response function on the power output of the system since it should contain the main acoustic modes to be controlled in the secondary path. In the presence of a reflective surface, there are additional resonances and the optimum length of the impulse response shall be long enough to include them for better stability and performance. Also, the orientation angle of the reflective surface can be selected to optimise the control performance of active noise control systems.

Acknowledgments

The first author acknowledges the postgraduate bursary received from the Tertiary Education Commission, for carrying out this work.

REFERENCES


