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ACOUSTICAL LETTER

ARMA modeling of a room transfer function at low frequencies

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1. Introduction

Efficient modeling of a room transfer function (RTF) is useful for many applications, such as acoustic echo cancellers and active noise controllers. An MA model (FIR filter) is widely used for modeling an RTF. The MA model, however, requires a large number of filter taps to model an RTF in a room with a long reverberation time. On the other hand, an ARMA model (pole/zero model: IIR filter) is expected to reduce the number of filter taps, since poles with few taps can express the resonance characteristics that cause long reverberation.[1] There have been many studies on ARMA modeling of an RTF, but they did not report that the number of filter taps was effectively reduced by the ARMA model.[2,3] The reason is probably that they studied ARMA modeling of an RTF for a wide frequency band where the mode density of a room is high, *i.e.*, the number of poles is large. In this paper, we discuss the ARMA modeling of an RTF focusing on the low frequency band where the mode density is low.

2. Pole and zero modeling of an RTF

The RTF between a source and a receiver can be represented using a z-transform as

$$H(z)=\frac{Cz^{-Q_1}\sum_{i=1}^{Q_2}(1-q_i z^{-1})}{\prod_{i=1}^{P}(1-p_i z^{-1})}, \qquad (1)$$

where C is a constant, p_i are poles, q_i are zeros, and P and Q ($Q=Q_1+Q_2$) are their orders (numbers of poles and zeros), respectively. This pole/zero model corresponds to the following ARMA model equation in the time domain.

$$y(k)=\sum_{i=1}^{P} a_i y(k-i)+\sum_{i=0}^{Q} b_i x(k-i), \qquad (2)$$

where a_i are AR coefficients and b_i are MA coefficients.

Assuming that the poles correspond to the resonance characteristics of a room, the number of poles N_f in the frequency band from 0 to f Hz is twice the number of resonances,[4] *i.e.*,

$$N_f=2\times\frac{4\pi}{3}\frac{V_0}{c^3}f^3, \qquad (3)$$

where V_0 is the volume of the room and c is the velocity of sound. The number of zeros is assumed to be equal to the number of poles.

3. Measured impulse responses

Impulse responses were measured in an experimental room, changing the reverberation time. The room was rectangular with a volume of 87 m^3. The reverberation time was set to 0.3, 0.36, 0.55, 1.6, and 2.4 s in the 500 Hz octave band by adding or removing absorbing materials to or from the walls. The upper frequency of the signal bands was changed to 100, 200, 300, 400, 500, 600, 800, and 1,000 Hz. The lower frequency of the bands was fixed to 60 Hz. The sampling frequency was 2.5 times the upper frequency of the frequency band. An example of the impulse responses is shown in Fig. 1.

4. ARMA modeling of the measured impulse responses

The measured impulse responses were modeled by a series-parallel type ARMA model as shown in Fig. 2. The ARMA model coefficients were estimated using the RLS algorithm[5] so as to minimize the error $e(k)$ between the real echo and the estimated echo. The order of the ARMA model ($P+Q$) was determined such that the power of the error $e(k)$ normalized by the power of the real echo $y(k)$ was -40 dB.

Figure 3 shows experimental results. The vertical axis represents the orders of the ARMA and the MA models that give a ratio of the error power to the real echo power of -40 dB. The horizontal axis represents the tap length of the measured impulse responses where the reverberation level drops by -40 dB. Since the order of the MA model directly corresponds to the tap length of the impulse responses, the MA model requires as many taps as the impulse response has. On the other hand, the order of the ARMA model is found to be smaller than that of the MA model, especially for the low frequency band. For example, when modeling an impulse response whose band is from 60$\sim$200 Hz for a reverberation time of 1.8 s, the MA model requires 600 taps, but the ARMA model requires only 240 taps. In each frequency band, when the reverberation time is long, the ARMA model can effectively reduce the orders. These results show that the ARMA model is more effective in the low frequency band and for long reverberation times for reducing the number

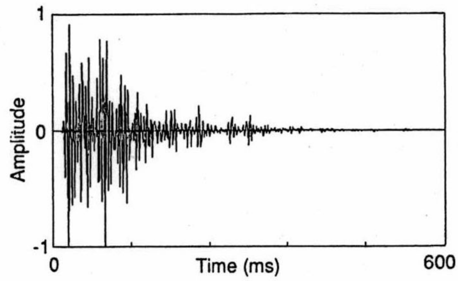

Fig. 1 Example of the measured impulse responses. The sampling frequency was 750 Hz, and the frequency band was 60~300 Hz.

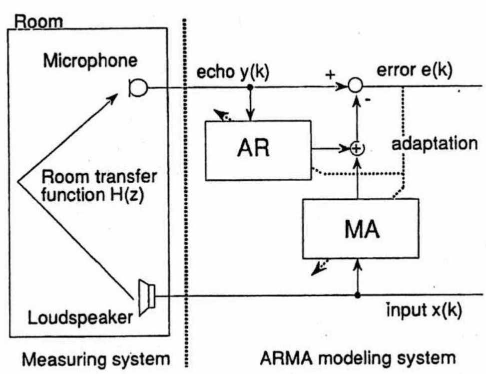

Fig. 2 Modeling of an RTF by a series-parallel type ARMA model.

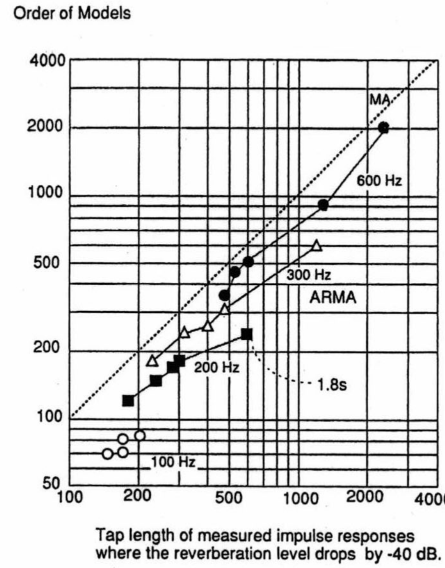

Fig. 3 Order of the ARMA and MA models versus the tap length of the measured impulse responses. The tap length of the impulse responses was determined as the number of taps when the reverberation level drops by -40 dB.

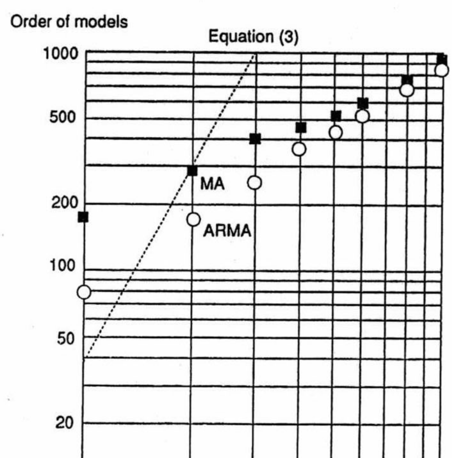

Fig. 4 Orders of the ARMA and MA models versus the upper limit of the frequency band. The reverberation time was 0.55 s.

of taps than the MA model.

Figure 4 shows the orders of the ARMA and MA models that give -40 dB residual echo power versus the upper limit of the frequency band for the reverberation time of 0.55 s. Here, the dashed line indicates the theoretical orders of the ARMA model, which were calculated by Eq. (3).

In the lower frequency band, the order of the ARMA model is smaller than that of the MA model. For example, when the upper frequency was 100 Hz, the order of the ARMA model was about half the order of the MA model. Although the theoretical order of the ARMA model increases in proportion to the third power of the upper frequency, the order estimated from the measured impulse response increases less rapidly. We believe that the differences between theory and estimation occur because several poles are degenerated and because the poles having low Q-factors can be ignored for the -40 dB error power.

5. Conclusions

The room transfer functions in the low frequency band were modeled by the ARMA model. We studied the relationships between the frequency band, reverberation times, and the order of the ARMA model. The order of the ARMA model is smaller than that of the MA model at low frequencies, and the difference becomes greater as the reverberation time becomes longer. For example, the ARMA model was able to reduce the order by about 40% (240/600) of the order of the MA model for a room with a volume of 87 m^3 in the frequency band of 60$\sim$200 Hz and a reverberation time of 1.8 s. Therefore, the ARMA model is effective for active noise control at low frequencies and for the low frequency band of subband acoustic echo cancellers.

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