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AURAL EFFECTS OF AN ACOUSTIC ECHO CANCELLER WITH SHORTER TAP LENGTH THAN REVERBERATION TIME

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ABSTRACT
This paper relates to the examination of an acoustic echo canceller tap length for speech communication systems. An adaptive filter is used for the acoustic echo canceller and its performance depends on the filter tap length. But, the necessary minimum tap length is still not clear. This paper analyzes the necessary tap length subjectively by listening tests. The subjects spoke by themselves and listened to the error signal produced by a computer simulation system. Differential limen of the tap length was calculated statistically. Reverberation time and SN ratio of the error signal were varied as the parameter. Results were that tap length depends on both reverberation time and SN ratio but effect of SN ratio is somewhat mild.

1 - INTRODUCTION

Use of hands-free telecommunication system by microphones and loudspeakers is going to be familiar, because it brings more natural conversation environment to not only telephone systems but also personal computer network systems. However, thus system includes a problem due to the acoustic echo by coupling between the microphone and the loudspeaker. It results uncomfortable communication and occasionally the howling.

The acoustic echo canceller, which uses adaptive digital filter, is a good solution to solve the problem. The performance of the acoustic echo canceller depends on the adaptive filter tap length. But, we still do not know the relationship between the performance of the acoustic echo canceller nor its filter tap length as a function of the acoustic environmental condition.

This paper examines the relationship by subjective listening tests. The subjects spoke by themselves and listened to the error signal to examine differential limen. The reverberation time in the room and SN ratio of the error signal were varied as the parameter. Differential limen was estimated by the results.

2 - ACOUSTIC ECHO CANCELLER

Fig. 1 shows the block diagram of acoustic echo canceller. Adaptive digital filter (FIR type) is used by the acoustic echo canceller. In this paper, NLMS (Normalized Least Mean Square) algorithm by *Eq.* (1) is used for adaptive algorithm [1].

$$\mathbf{h}(k+1) = \mathbf{h}(k) + \frac{\alpha}{\mathbf{x}^T(k)\,\mathbf{x}(k) + \beta}\mathbf{x}(k)\,e(k) \tag{1}$$

where $\alpha = 1$, $\beta = 0$.

Also, adaptive filter tap coefficients were set to be optimum by white noise before subjects spoke, and adaptation was stopped while subjects spoke.

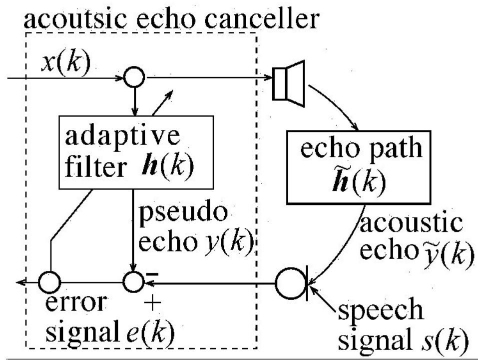

Figure 1: Block diagram of acoustic echo canceller.

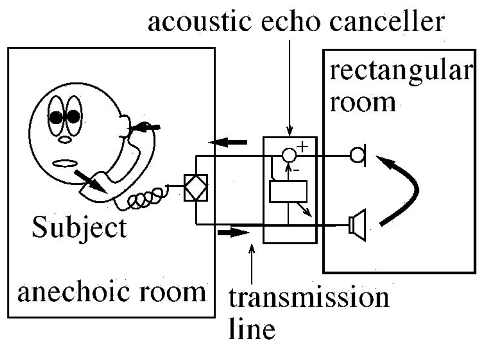

Figure 2: Block diagram of simulated system.

3 - ENVIRONMENTAL CONDITIONS

Fig. 2 shows the block diagram of simulated system model. A subject in an anechoic room who uses hand-set speaks to another person in rectangular room who uses hands-free telecommunication system. The person in rectangular room does not talk, so double talk does not occur. And signal delay and attenuation in the transmission line do not occur.

Impulse response of rectangular room was calculated by a digital computer [2]. Fig. 3 shows the position of microphone and loudspeaker.

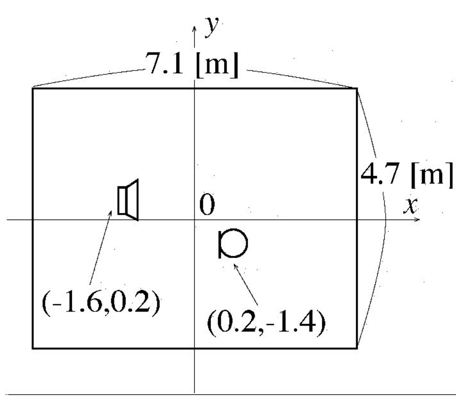

Figure 3: Position of microphone and loudspeaker.

4 - LISTENING TESTS

4.1 - Methods

Fig. 4 shows real-time experiment system which is used for listening tests [3]. It includes two digital filter boards. One is used to calculate acoustic echo in the rectangular room. The other is used as an acoustic echo canceller to calculate pseudo echo. Error signal is calculated by subtracting pseudo echo from the acoustic echo and added white noise.

Subject speaks a Japanese sentence which is "bakuon ga kougen ni hirogaru" and judges that he could recognize the error signal or could not. Adaptive filter tap length is varied at random after subject speaks and the same tap length is used 3 times for each subjects.
The differential limen is determined from judgment ratio p which is calculated by *Eq.* (2) after experiment.

$$p = \frac{(\text{number of "could not listen" a nswer})}{3^{*}\,(\text{number of subjects})} * 100\,[\%] \tag{2}$$

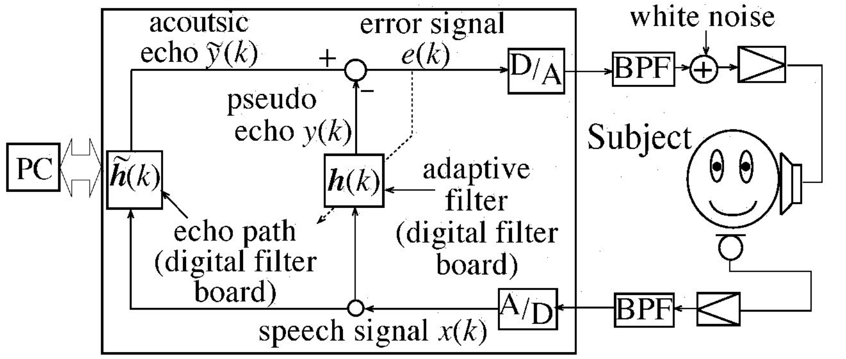

Figure 4: Block diagram of real-time experiment system.

4.2 - Parameters

Table 1 shows parameters of real-time experiments.

Speech level	94 [dB]
Listening level	84 [dB]
SN ratio	43 [dB] at t_{60}=0.1 [s] 22, 28, 31, 43 [dB] at t_{60}=0.2 [s]
Reverberation time (t_{60})	0.1, 0.2 [s]
Tap length	550, 600, 650, 700, 750, 800, 850 [taps] at t_{60}=0.1 [s] 1000, 1100, 1200, 1300, 1400, 1500, 1600 [taps] at t_{60}=0.2 [s]
Subjects	11 males

Table 1: Parameters of real-time experiments.

5 - RESULT

Fig. 5 and Fig. 6 show the results of the real-time experiments, and Table 2 shows the tap length at differential limen and its decrease ratio calculated by *Eq.* (3) and the error signal level.

$$(\text{decrease ratio}) = \frac{(L_{t60} - L_d)}{(L_{t60})} * 100\,[\%] \tag{3}$$

where L_d is tap length at differential limen, and L_{t60} is equivalent tap length to reverberation time in the room.
About relationship between reverberation time and tap length, Table 2 shows that tap length is shorter when reverberation time is shorter. So, cost reduction enables when reverberation time is short.
Table 2 shows the relationship between tap length and SN ratio. We see the allowable tap length is shorter when SN ratio is smaller, or noise is louder. But error signal varied 10 [dB] when SN ratio varied 21 [dB]. So, the influence of SN ratio upon the tap length is somewhat mild.

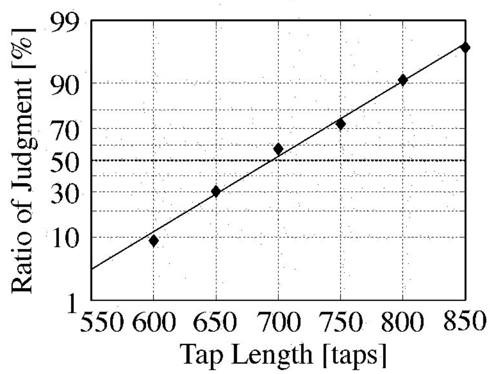

Figure 5: Result at t_{60}=0.1 [s].

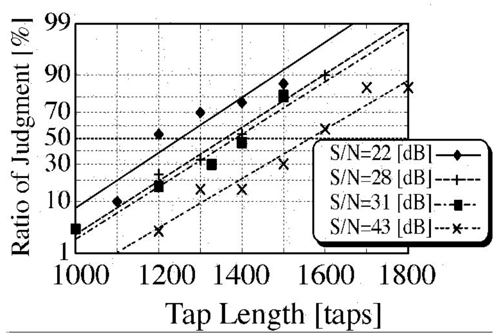

Figure 6: Results at t_{60}=0.2 [s].

Reverberation time [s]	S/N ratio [dB]	Tap length at differential limen [taps]	Decrease ratio in tap length [%]	Error signal level [dB]
0.1	43	695	13.2	21
0.2	22	1269	20.7	27
	28	1357	15.2	25
	31	1381	13.7	24
	43	1560	2.3	17

Table 2: Tap length, decrease ratio of tap length and error signal level at differential limen.

6 - CONCLUSIONS

This paper clarified that the listening tests were valuable to determine adaptive filter tap length in the acoustic echo canceller. The experimental results are as follows: 1) Adaptive filter tap length mainly depends on reverberation time in a room, and the influence of SN ratio is somewhat mild. 2) Shorter reverberation time enables more decrease in adaptive filter tap length, or lower costs for acoustic echo canceller.

In future work, more listening tests nearer to the practical usage, such as use of real room reverberation or with delay in transmission line will be examined.

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