INFLUENCE OF TIME-VARIANCE IN AUDITORIUM ON IMPULSE RESPONSE MEASUREMENT

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Satoh Fumiaki*[1]; Nagayama Mitsuru*[1]; Tachibana Hideki*[2]
*1 Chiba Institution of Technology
Tsudanuma 2-17-1, Narashino-shi, Chiba
244-0806 JAPAN
*2 Institute of Industrial Science, Univ. of Tokyo
Komaba 4-6-1, Meguro-ku, Tokyo
153-8505 JAPAN
Tel: +81 47 478 0492*[1]; +81 3 5452 6424*[2]
Fax +81 47 478 0499*[1]; +81 3 5452 6426*[2]
E-mail: f_satoh@pf.it-chiba.ac.jp*[1]; tachibana@iis.u-tokyo.ac.jp*[2]

ABSTRACT

For the measurement of room impulse response by MLS and TSP methods, synchronous averaging technique is often used to improve the S/N ratio. In these measurements, however, the time-variance of the atmosphere is a very serious problem. This problem was examined experimentally by focusing on reverberation time obtained by the integrated impulse response method. The reverberation time obtained from the impulse response measured with synchronous averaging was compared with that without synchronous averaging. As a result, it was indicated that the synchronous averaging becomes dangerous for the measurement of reverberation time under such a slight temperature changes as 0.1 degree.

INTRODUCTION

In the measurement of room impulse response, the synchronous average technique is often used to suppress the influence of extraneous noise. This technique is effective only when the assumption that the sound propagation system is linear and time-invariant is valid. Actually, however, even in ordinary rooms, it is usual that the air is continuously moving and the temperature is changing more or less and therefore the assumption of time-invariant has to be carefully considered. On this point, some researches have been conducted to date [1]~[3]. We also have been examining the influence of such time-variance on the measurement of room impulse response. In Forum Acusticum Berlin (1999) [4], we presented a paper on the results of basic experiments performed in a reverberation room. In this experiment, the air in the room was artificially excited using electric fans and the influence of time-variant condition on room impulse response was examined. After that, we performed similar experiments in several halls in real condition and the results are presented and discussed in this paper. As the indicator to express the influence of the time-variance, reverberation time determined by the integrated impulse response method was used and the value obtained from the impulse response measured by 8 times synchronous averaging was compared with that without averaging. The extent of the time-variance in the medium was examined by calculating short-term running cross-correlation function between each impulse response before synchronous averaging.

FIELD MEASUREMENT

Impulse Response and Reverberation Time

For the measurement of room impulse response, the time stretched pulse (TSP) method (sweep pulse method) using a signal of 1.35 s duration time was adopted in this study [5]. Reverberation decay was obtained by the integrated impulse response method and the reverberation time was read from the range from –5 dB to –35 dB in the decay process. The S/N ratio was relatively poor in octave band of 250 Hz and the value in this band was obtained in the range from –5 dB to –25 dB.

Field Measurement and Synchronous Averaging

The field measurements were performed in five kinds of sound field in three halls as shown in Table 1. In each measurement, the sound source position and the receiving position were fixed. The TSP signal was repeatedly radiated from a dodecahedral loudspeaker system. About 10 pulses were radiated approximately every 6 seconds (this is a segment), and this segment was repeated at approximately 5 minute intervals. The responses at the receiving position were recorded onto a DAT and the synchronous averaging was performed later in the laboratory. For the processing of synchronous averaging, 8 responses not contaminated by extraneous noises were chosen among the recordings of each segment. Table 1 shows the measurement conditions in each sound field under test. For example, in the case of A, the TSP signal was radiated 160 times and 15 impulse responses were obtained by 8 times synchronous averaging and the total time for the measurement was 85 minutes.

Table 1 Specifications of sound fields and measurements

sound field	Capacity [seats]	Volume $[m^3]$	R.T. in 500 Hz [sec.]	Number of the times of TSP signal radiation	Number of segments	Total times [min.]
A	714	6,770	1.7 (with reflector)	160	15	85
B	714	6,700	1.2 (without reflector)	126	11	77
C	1,802	19,560	2.4 (with reflector)	68	7	38
D	1,802	19,560	1.8 (without reflector)	40	4	33
E	22,000	320,000	2.1	30	3	34

TIME-VARIANCE IN THE REAL SOUND FIELD

As can be seen from Table 1, 40 impulse responses with 8 times averaging were obtained in total through the measurements in 5 sound fields. Reverberation time was calculated for those data and compared with the value without synchronous averaging. Figure 1 shows the results, in which the vertical axis is ER (error ratio) of reverberation time defined eq.1. Two cases in which ER exceeds 10% in high frequency range are seen in the figure.

$$\mathrm{ER} = \frac{(\text{R.T. with 8 times averaging}) - (\text{R.T. without averaging})}{(\text{R.T. without averaging})} \times 100 \quad [\%] \quad \cdots\cdots \quad \text{eq.1}$$

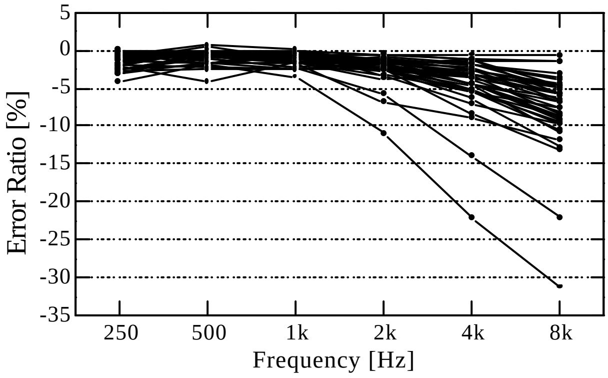

Figure1 Error ratio of reverberation time cause by 8 times synchronous averaging

CHARACTERISTICS OF TIME-VARIANCE

Since it is impossible to observe the temperature and air fluctuations in the total sound field in detail, acoustical data were used to estimate the extent of the time-variance in the medium. That is, the short-term running cross-correlation function between each impulse response before synchronous averaging was calculated for 8k Hz octave band. The calculation was performed for every 2.5 ms using 10 ms time window. Figure 2 shows two examples of the time-lag (t) of the maximum value in the cross-correlation function.

Figure 2(a) shows the result of the calculation between the 3rd and the 11th impulse responses in sound field A, in which it is seen that the value of τ are scattered around $\tau = 0$. From this result, the time-variance in this case might be attributed to the air fluctuation. For reference, Fig.3(a) shows the result of the experiment performed in a reverberation room using electric fans to excite the air and the similar fluctuation of τ was observed as in the result of this time.

Figure 2(b) shows the result of the calculation between the 64th and the 73rd impulse responses in sound field A, in which monotonous decrease of τ is seen. In this case, the change of τ might be attributed to the temperature change in time. In Fig.3(b), both of instantaneous fluctuation and monotonous increase are seen in the change of τ. In this case, air fluctuation and gradual temperature change might occur at the same time.

As mentioned above, it has been indicated that the change of τ might be effective to indicate the extent of time-variance in the medium and the global temperature change might be estimated from the gradual change of τ. In Fig.4, the black circle indicates the temperature changes from the beginning of the measurement in sound field A estimated this way. In this figure, open square indicates the temperature measured at a point near the receiving position with a thermometer.

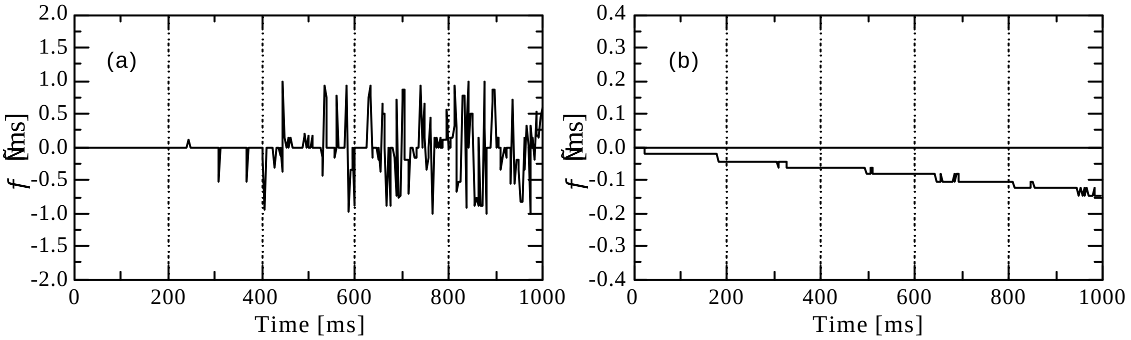

Figure 2 Two examples of the time-lag (τ) in sound field A
(a): Calculation result between the 3rd and the 11th impulse responses
(b): Calculation result between the 64th and the 73rd impulse responses

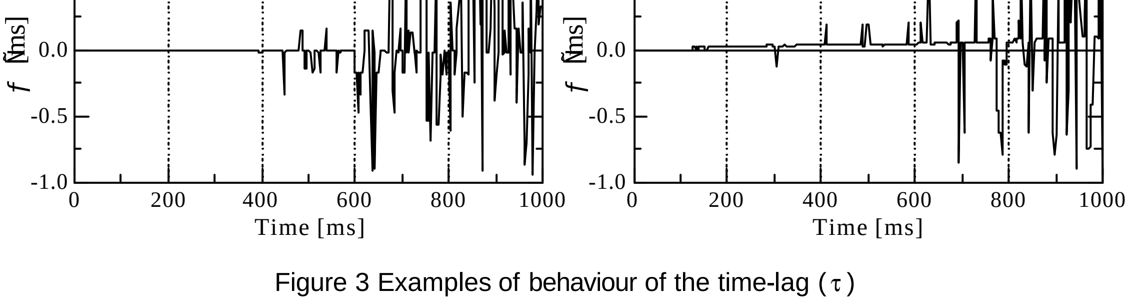

Figure 3 Examples of behaviour of the time-lag (τ)
(a): Experiment result performed in a reverberation room using electric fans
(b): Air fluctuation and gradual temperature change occur at the same time

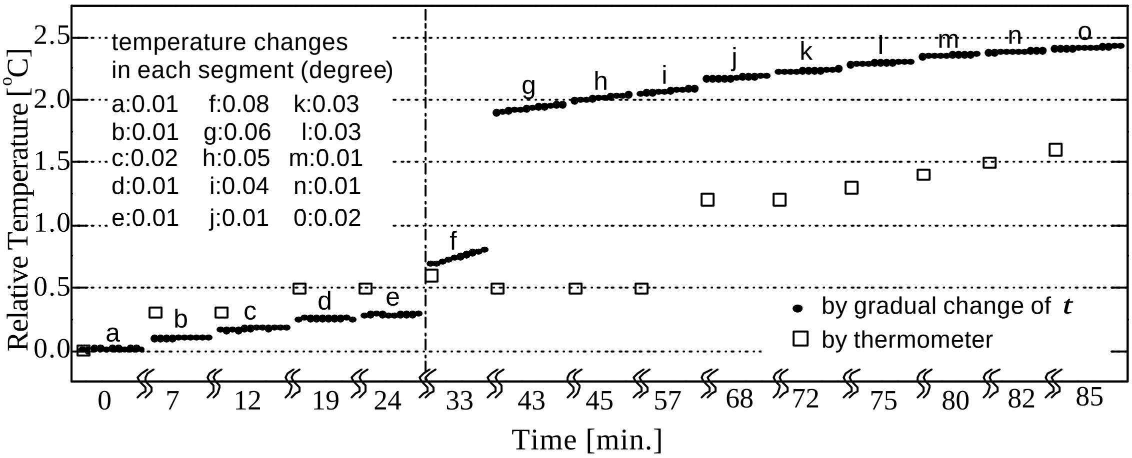

Figure 4 Estimated temperature changes in sound field A

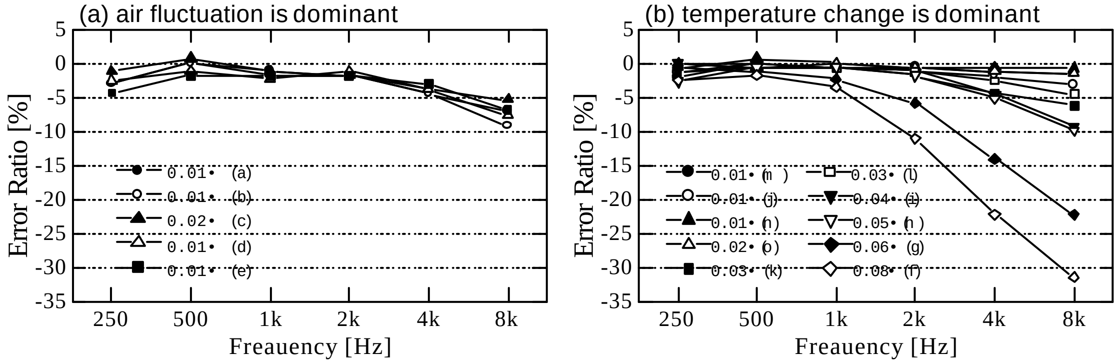

Figure 5 Error ratio of reverberation time caused by 8 times synchronous averaging
(a): In case where air fluctuation is dominant (time-segments **a** to **e**)
(b): In case where temperature change is dominant (time-segments **f** to **o**)

INFLUENCE OF THE TIME-VARIANCE ON REVERBERATION TIME MEASUREMENT

Air Fluctuation

In Fig.4, it can be considered that the influence of air fluctuation was dominant in the first 30 minutes (time-segments **a** to **e**) by observing the change of τ. The values of ER for the reverberation time in this case are shown in Fig.5(a). (The reverberation time was read from the impulse response obtained by 8 times synchronous averaging.) In this case, the values of ER are within 10 % for all frequency bands.

Temperature Change

In Fig.4, it can be considered that the influence of temperature change was dominant for the time-segments **f** to **o**. The values of ER for the reverberation time in this case are shown in Fig.5(b). (The reverberation time was also read from the impulse response obtained by 8 times synchronous averaging.) In this case, the value of ER is within 10% for all frequency bands under the condition that the temperature change was less than 0.05 degrees, whereas the value remarkably increased when the temperature change exceeded 0.05 degrees.

TSP METHOD USING A LONG DURATION SIGNAL

TSP Method Using Signal with Long Duration Time

As another method to get high S/N ratio than synchronous averaging, the method using a TSP signal with long duration time was applied. To examine this method, a long TSP signal (L-TSP) with 10.8 seconds was used and the measurement results were compared with the results obtained using the TSP signal with 1.35 seconds (S-TSP) which was used in the previous measurements. Figure 6 shows the comparisons of reverberation decay curves obtained by using (1) S-TSP without synchronous averaging, (2) S-TSP with 8 times synchronous averaging and (3) L-TSP (without synchronous averaging). In this result, it can be seen that almost the same reverberation decay was obtained in the cases of (1) and (3) and almost the same S/N ratio was obtained in the cases of (2) and (3).

Comparison with the MLS Method

For the measurement of room impulse response, MLS technique is also being used. In this method, synchronous averaging is used and therefore the influence of time-variance is also serious problem. In our investigation, it has been found that the influence of time-variance is more severe for the MLS method than for the TSP method. Figure 7 shows the results of the experiments performed in a reverberation room and a concert hall. (They were presented at the Forum Acusticum Berlin, 1999). In Fig.7(a) and (b) which are the results obtained in a reverberation room under the conditions of fan-on and –off by the MLS method and the TSP method, respectively. In these results, it is seen that the result by the MLS method is apt to be much more influenced by air fluctuation than the case using the TSP method. Figures 7(c) and (d) shows the results measured in a concert hall and a similar tendency can be seen in this case, too.

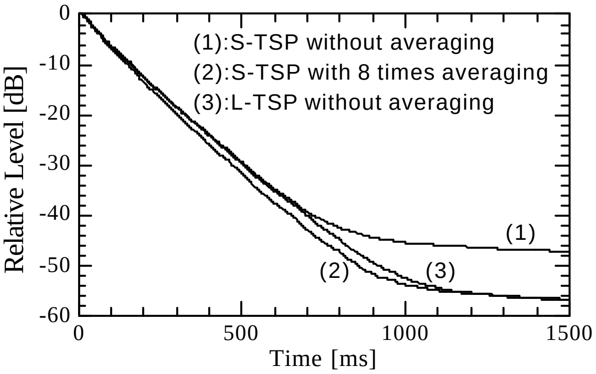

Figure 6 Comparisons of reverberation decay curves

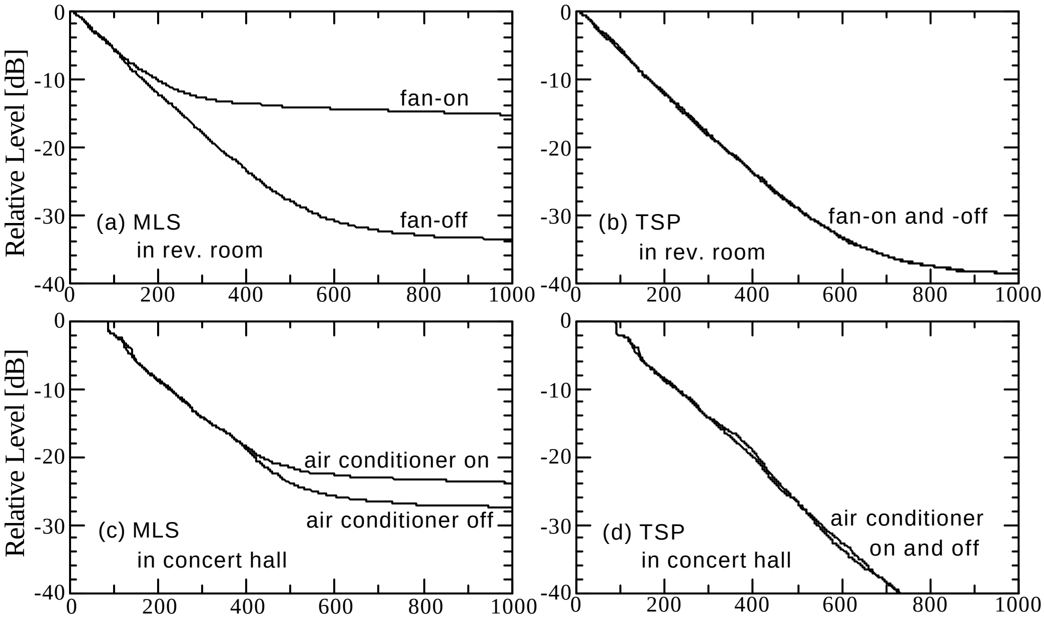

Figure 7 Comparison of S/N ratio

CONCLUSIONS

The results obtained in this study indicates that the synchronous averaging technique to obtain high S/N ration in the measurement of room impulse response must be carefully considered when the time-invariance condition is not guaranteed. As a method to examine the extent of time-variance in the medium, the short-term running cross-correlation technique mentioned above is effective. When making room impulse response measurement under the condition that the time-invariance condition is uncertain, the TSP method using a long duration time is useful.

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