SUBJECTIVE EXPERIMENT ON SPEECH-RATE OF EMERGENCY EVACUATION ANNOUNCEMENT IN A TUNNEL

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ABSTRACT

For the improvement of speech intelligibility (easiness of hearing) of the public address system for emergency evacuation in a tunnel, the authors are proposing the application of successive time-delay technique and have performed an experimental investigation in an actual tunnel. In the experiment, by comparing the difference of speech intelligibility between the conditions with/without time-delay, the effect of the technique has been examined. In an anechoic room, subjective experiments on speech intelligibility have been performed using the 6-channel recording/reproduction technique by which natural spatial impression can be realized with 3-dimensional information. At the center point of the reproduced sound field (hearing position), hearing tests have been performed. As a result, the effectiveness of the successive time-delay technique has been confirmed. In this paper, the experimental results for the influence of speech-rate of the emergency announcement and that of the reverberation in the tunnel on speech intelligibility are presented.
1 INTRODUCTION

As a means to improve speech intelligibility of public address system for emergency evacuation in a tunnel, authors proposed an idea to apply the successive time-delay technique to an array of loudspeakers in a road tunnel and investigated the applicability of this technique experimentally in a real tunnel under construction [1], [2]. The experimental results indicated that speech intelligibility can be considerably improved by applying the time-delay technique appropriately. Furthermore, the sound field in a tunnel is generally very reverberant, and it is likely that the speech intelligibility of evacuation announcement is influenced by the speech-rate. In this paper, the successive time-delay system for the emergency evacuation announcement system is reviewed and the results of psycho-acoustical experiments on the effect of speech-rate of the announcement and that of the reverberation are presented.

2 FIELD EXPERIMENT IN A TUNNEL

2.1 Application of Time-delay Technique

Field experiment was performed in a highway tunnel just before its completion in July, 2004. Figure 1 shows the diagram of the public address system using the successive time-delay technique set in the tunnel. Near the wall inside the tunnel, five horn-type directional loudspeakers (see Fig.2) were set at an interval of 150 meters. In this reproduction system, the speech signal fed to respective loudspeakers was delayed by $\tau = D_i / c$ compared to that for the adjacent upper loudspeaker (the left one in the figure), where $D_i$ is the distance between the two adjacent loudspeakers and $c$ is the speed of sound.

Fig. 1. Diagram of the public address system in a tunnel with successive time-delay function.
2.2 Measurement of Impulse response

At the five positions between the two loudspeakers shown in Fig.1 \((d=25, 50, 75, 100, 125 \text{ m})\), impulse response measurements were performed under both of the conditions that each loudspeaker was driven separately and that all loudspeakers were driven simultaneously with/without time-delay. These measurements were performed using the swept-sine technique. As the receiving system, a 6-channel microphone system including an omni-directional microphone was used (see Fig.3) [3]. Figure 4 shows the comparison of the omni-directional impulse responses measured at the measurement position, \(d=100 \text{ m}\), (a) without time-delay and (b) with time-delay. In these results, it is clearly seen that the direct sound is converged by the time-delay processing.

3 TEST SOUNDS

3.1 Speech-rate

For the test sounds, the directional impulse responses measured at the position \(d=100\text{m}\) in the tunnel through the 6-channel microphone system and dry-sources of evacuation announcement with four-step different speech-rate were convolved. The fastest speech-rate among them is a common rate for speech in radio broadcast and the slowest rate is common in the announcement in stadiums with big volume.
3.2 Reverberation

To examine the influence of the reverberation in the tunnel on speech intelligibility, the reverberation time of the directional impulse responses measured in the tunnel under the conditions that each loudspeaker was driven separately were artificially shorten in three steps. For the test sounds, the modified directional impulse responses with/without time-delay and dry-sources of evacuation announcement with two-step different speech-rate were convolved.

4 PSYCHO-ACOUSTICAL EXPERIMENTS ON “DIFFICULTY OF HEARING”

To examine the effects of speech-rate and reverberation on speech intelligibility, two kinds of hearing tests were performed in an anechoic room; Experiment 1 is for the effect of speech-rate of the announcement and Experiment 2 is for the influence of reverberation in the tunnel.

4.1 Experimental Procedures

In this kind of hearing test, it is desirable that the sound can be heard as in the real sound field with 3-dimensional spatial impression, and the 6-channel recording/reproduction method [3] was applied in these experiments. Figure 5 shows the diagram of the system, in which six loudspeakers are set orthogonally in an anechoic room and the six channel signals convolved for the hearing test are reproduced from respective loudspeakers. When hearing the reproduced sounds at the center position, we can get natural auditory sensation (see Fig.6).

In these tests, the subject was asked to judge the audibility of the evacuation announcement in 6-step categories: “the contents can not be understood at all” (6), “extremely difficult to hear” (5), “very difficult to hear” (4), “moderately difficult to hear” (3), “a little difficult to hear” (2) and “not difficult to hear at all” (1). In each experiment, each test sound was reproduced twice in random order. For each test sound, the arithmetic average of the scores obtained by the scale rating was calculated.

![Diagram of 6-channel recording/reproduction system.](image)

(A) 6-channel recording system       (B) 6-channel reproduction system (in an anechoic room)

Fig. 5. Diagram of 6-channel recording/reproduction system.
4.2 Experiment 1: “Effect of Speech-rate”

In Experiment 1, the speech audibility test was performed by changing the speech-rate of the announcement in four steps under the conditions of with/without time-delay. As the test subjects, ten Japanese from 21 to 31 years old participated in this experiment.

The test results are shown in Fig. 7. In the results, it is clearly seen that the speech intelligibility has been significantly improved in all speech-rate conditions when the time-delay technique was applied. Under the condition of without time-delay, the speech intelligibility was gradually improved with the increase of speech-rate (becoming slower), whereas under the condition of with time-delay the score was kept around 2 “a little difficult to hear” except for the fastest speech-rate condition. After the experiment, a subject commented that the slowest speech-rate condition was easy to listen but tension under such a dangerous situation can not be felt.

4.3 Experiment 2: “Influence of Reverberation in a tunnel”

To examine the effect of the sound absorption treatment inside the tunnel, in Experiment 2, the speech audibility test was performed using test sounds mentioned above, the reverberation time of the impulse response in three steps and speech-rate in two steps. As the test subjects, five Japanese from 21 to 31 years old participated in this experiment.

The test results are shown in Fig. 8. In the results, it is clearly seen that the speech intelligibility has been significantly improved by the time-delay technique in both of the speech-rate conditions. Under the condition with time-delay, it can be seen that the speech intelligibility was improved by shortening the reverberation time.
CONCLUSIONS

For the design of P.A. system for emergency evacuation announcement in a reverberant tunnel, subjective experiment on speech intelligibility was performed and the following results have been obtained.

1. The successive time-delay technique is very effective to improve the speech intelligibility of the announcement in a tunnel.
2. Regarding the speech-rate of the announcement, it has been found that the speech intelligibility improves with the increase of the speech-rate but it should also be proper for such a tense situation as fire emergency.
3. In order to further improve the speech intelligibility, it is effective to control the reverberation in the tunnel by any sound absorption treatment.

REFERENCES