Development of a prototype system to evaluate of contribution rate of each noise source in road traffic noise

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ABSTRACT

In Japan, the achievement of environmental standards for noise is evaluated by long-term average sound level. Therefore, it is quite difficult to identify the factors of exceeding the regulatory limit. This study aims to develop a system that enables to conduct a separate measurement of each noise source and an evaluation of each source. By the evaluation of contribution rate of each noise source in roadside noise, it is possible to define priorities for countermeasures to deal with.

As the first step of the system development, this paper introduces the development of prototype system, reporting on the configuration of the system and the results of verification tests.

Keywords: Road Traffic Noise, Noise source localization, Beamforming

I-INCE Classification of Subjects Number(s): 13.2

1. INTRODUCTION

The achievement of environmental standards for noise generally shows a trend of moderate improvement in Japan (1). However, areas near arterial roads are still in severe conditions. Figure 1.1 illustrates how measurements are made in Japan for the environmental standards of road traffic noise. The current method just measures the overall traffic noise level and cannot measure each noise level emitted by every single vehicle. It is quite difficult to identify the factors of exceeding the regulatory limit. Then, this study aims to establish a system that enables to conduct a separate measurement of each noise source and a systematic evaluation of each source. By the evaluation of contribution rate of each noise source in roadside noise, it is possible to define priorities for countermeasures to deal with. Figure 1.2 gives a concept of the system used for development in this study. The system developed in this study is a noise visualization unit which consists of microphone arrays and a camera to assess the noise levels by the location of noise source. In addition, the system is programmed to automatically detect the vehicle type from a noise source distribution based on the visualized results and a recorded image. The noise levels obtained by these procedures are sorted according to vehicle type and noise source and then the contribution rate to roadside noise was automatically assessed.

This paper introduces the development of a prototype system, reporting on the configuration of the system and the results of verification tests. Beamforming method is adopted as a noise source localization method which takes into account the reflected waves.

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Figure 1.1 – View of road traffic noise being measured

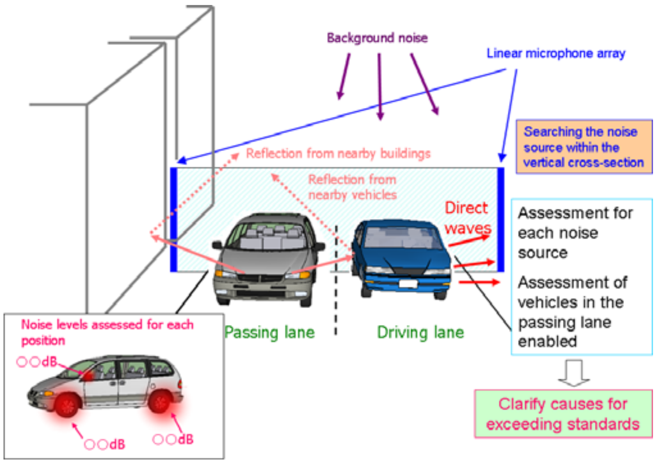

Figure 1.2 – Concept of new measurement method

2. BEAMFORMING METHOD CONSIDERING REFLECTED WAVES

In this study, an extended beamforming method (delay-and-sum) is adopted for noise source localization. In a conventional beamforming method, signal processing is performed by assuming that all measured signals are direct waves. In our study, signal processing which consider propagation up to double reflected waves is performed. Figure 2.1 shows schematically the propagation of direct pulses and reflected pulses from the ground, from a noise source at position S to observation points M. Assuming a single pulse is emitted from the location S, the measured signal from each microphone (M1~M4 in Figure 2.1) will appear as in Figure 2.2. At each microphone measure the direct pulse wave and the reflected pulse wave with a time difference. The conventional beamforming method which considers just the direct wave is shown schematically in the upper diagram in Figure 2.3. From this diagram, pulse wave was observed as four times the size of the original signal. According to the center diagram in Figure 2.3, if reflected wave is taken into account, the pulse wave can be observed as eight times the size of the original. On the other hand, if no such noise source exists at the position S, any emphasized signals are observed as shown in the lower diagram in Figure 2.3. According to this principle, the intended signal is observed as being emphasized more so than conventional beamforming method.

In our study, the beamforming method which considers up to double reflections is adopted. The propagation path which considers up to double reflections is derived using the image source method. In this paper, the position of reflective objects and their cross-sectional size are assumed to be known beforehand. Sound reflection at reflective surfaces is assumed to be perfect reflection, so that distance attenuation has not been considered.

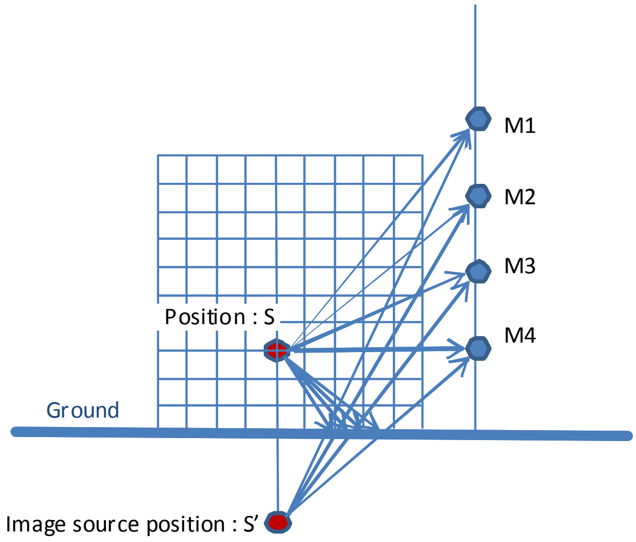

Figure 2.1 – How waves propagate from noise source S

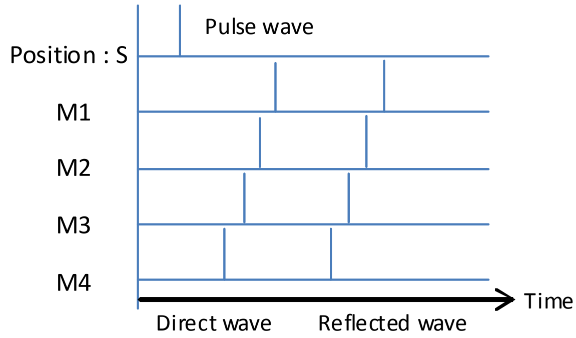

Figure 2.2 – Emitted single pulse and the signals observed at each measurement point in Figure 2.1

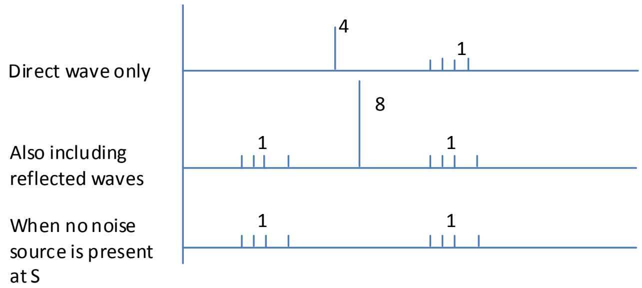

Figure 2.3 – Schematic diagram of the composite waveform by beamforming method
(Numbers in the figure shows relative magnitude of the signal.)

3. INDOOR EXPERIMENTAL TEST

An experimental test was performed using speakers in a hemi-anechoic room. Figure 3.1 shows the appearance of the speaker experiment. In the experimental test, two microphone arrays were prepared with 16 microphones arranged linearly at intervals of 0.12 m, and were placed at the points x = 0.0 m, and x = 2.5 m. A speaker was placed in the vicinity of an obstruction of width 0.9 m and height 0.3 m. Noise source distribution is calculated for vertical cross-section between the microphone arrays as shown in Figure 3.1.

Figure 3.2 shows a result of noise source localization which considered just direct waves. Figure 3.3 shows a result of beamforming method which considers up to double reflections. These figures were derived from the same data. In conventional beamforming method, the speaker was placed at the location slightly different from the actual location. This is due to reflection of the reflective object. On the other hand, in the results which considered reflections, the location where the speaker had been placed was indicated as noise source position precisely. From these results, spatial resolution of noise source localization was improved by accounting for reflections.

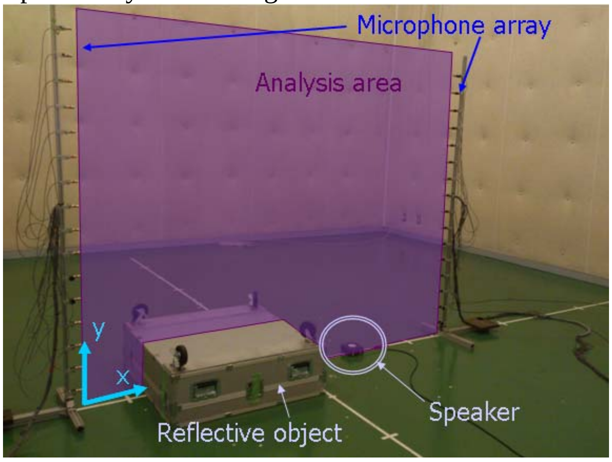

Figure 3.1 – Scene of the indoor speaker test

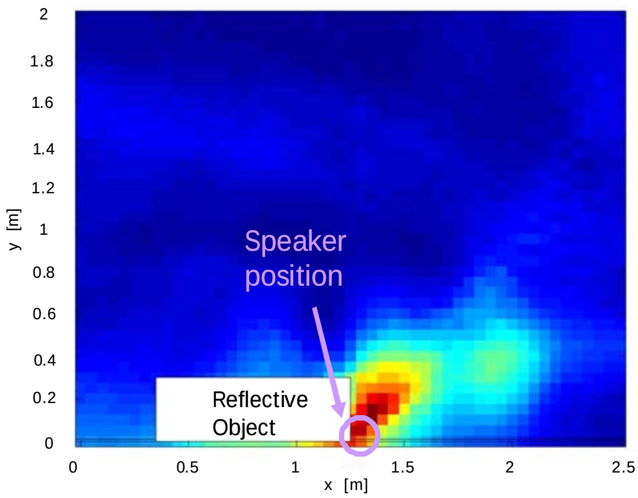

Figure 3.2 – Indoor test results considering just direct waves

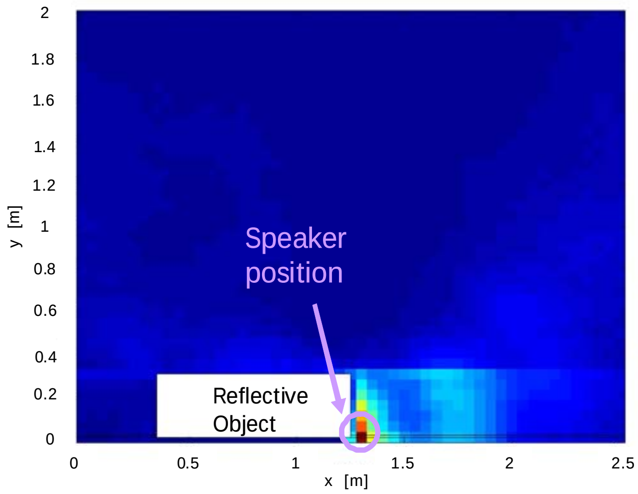

Figure 3.3 – Indoor test results considering up to two reflections

4. DEVELOPMENT OF A PROTOTYPE SYSTEM

Figure 4.1 shows a configuration diagram of the developed prototype system. The system consists of two microphone arrays, two line scan cameras, two data recording units, and two personal computers. Each one of these pairs was placed respectively on either side of the road. The Ono Sokki MI-1433 was used for the microphones, and the Ono Sokki-made MI-3111 was used for the preamplifiers. For the data recording units, the cDAQ-9178NI chassis produced by National Instruments was used in combination with the NI-9234 4CH A/D module. Line scan cameras AViiVA EM1 which were made by e2v were used to shoot passing-by vehicles in front of the microphone array. This camera has 512 pixels per line, and it was connected to the computer using Ethernet. The start times for data measurement was matched using a GPS signal in order to conduct precisely simultaneous measurements at each roadside.

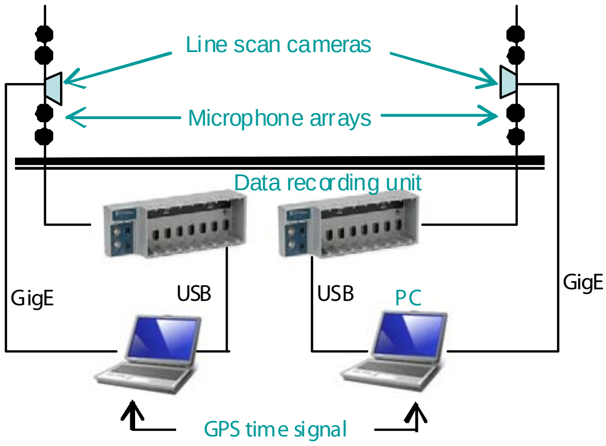

Figure 4.1 – System configuration diagram

5. OUTDOOR EXPERIMENTAL TEST

5.1 Overview of the experimental test

A verification test which studied vehicles driven at slow speed was carried out. Figure 5.1 shows how the outdoor driving test appeared. At this experimental test, two linear microphone arrays, which consisted of 12 microphones each of which was arranged at 0.15 m intervals, were installed on each side. At this test, noise source distribution was calculated only on an analysis line illustrated in Figure 5.1 at every 40msec. The experiment was done using a passenger car without any modifications. The vehicle was driven at a constant speed of 10km/h. The background noise level was about 48 dB.

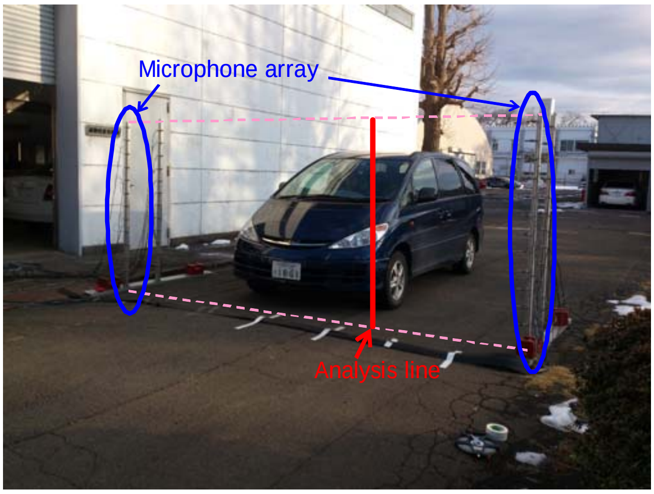

Figure 5.1 – Scene of the outdoor experimental test with running vehicle

5.2 Experimental results

To calculate propagation path up to double reflections, it is necessary to know about vehicle's size and location. In this study, it is assumed that the vehicle was driven through the center of the microphone arrays, and the vehicle size measured prior to running test was used to calculate noise source distribution, because the cross-sectional size of the passing vehicle cannot be measured with the present system. The position of the vehicle was found from the driving speed and the distance from the driving start position to the microphone array. Figure 5.2 shows a result of noise source localization on the analysis line. In this figure, horizontal axe indicates time and vertical axe indicates height. It can be seen that noise source locations were concentrated roughly in the vicinity of the tires and ground. The location where no vehicle exited was indicated as noise source position, because tire noise emitted back and forth. Therefore, more temporal resolution is required for the noise source localization method to evaluate each noise source.

Figure 5.2 – Result of noise source localization by prototype system

6. CONCLUDING REMARKS

To identify the factors of exceeding the regulatory limit of road traffic noise, an apparatus to visualize noise source of passing-by vehicle was developed. A beamforming method considering up to double reflections was adopted to improve the accuracy of noise source localization. An indoor speaker test was conducted to confirm the extended beamforming method. As a result, spatial resolution shows sufficient accuracy. A verification test of the prototype system was also conducted by using a low-speed driving vehicle and favorable results were obtained, however temporal resolution needs further improvement for more accurate noise source localization.

In future study, the system will be improved to acquire size of passing-by vehicles by using image processing to calculate propagation path considering reflection.

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