Consideration and case study using a time-difference-of-arrival directional device for occupational noise measurement

Naru Sato[1]
Norsonic AS
Gunnersbråtan 2, 3409 Tranby, Norway

Karl Henrik Ejdfors[2]
Norsonic AS
Gunnersbråtan 2, 3409 Tranby, Norway

Takeshi Nakaichi[3]
RION Co., ltd.
3-20-41, Higashimotomachi, Kokubunji, Tokyo 185-8533, Japan

Erlend Fasting[4]
Norsonic AS
Gunnersbråtan 2, 3409 Tranby, Norway

Lars Andreas Sæle[5]
Norconsult Norge AS
Kjørboveien 22, 1337 Sandvika, Norway

ABSTRACT

To protect worker's hearing in noisy workplaces, noise levels are measured periodically, and noise sources are located based on the results of recordings or video cameras. If the noise level is above a criterion level, noise abatement measures are taken, or workers are suggested to wear hearing protection. Measuring the noise level can be done simply by placing a sound level meter on the floor, but finding the noise abatement is a time-consuming task. It is necessary to listen to the recordings one by one or review the video to find the noise abatement. We believe that a simple method of estimating noise abatement is very useful, since some noisy workplaces do not allow recordings or video cameras for privacy and confidentiality reasons. In this paper, noise source identification using a time-difference-of-arrival directional device in an indoor environment is examined. The results are analyzed in the context of room properties such as reverberation time, dimensions, and device localization. The paper also reports on practical use-cases in actual sites.

[1] n-satou@norsonic.com
[2] kejdfors@norsonic.com
[3] nakaichi@rion.co.jp
[4] erlend.fasting@norsonic.com
[5] lars.andreas.saele@norconsult.com

1. INTRODUCTION AND BACKGROUND

To protect the hearing of workers, various regulations regarding noise exposure exist in countries around the world. Employers are obligated to measure the noise levels to which workers are exposed and, if necessary, provide soundproofing measures against noise reduction or require workers to wear hearing protection. In Norway, there are regulatory requirements to noise levels in the workplace. The required noise levels are dependent on which tasks the employee performs. And are given in the following table.

Table 1: Required noise level and each condition for noisy workplace in Norway.

	Worker group 1	**Worker group 2**	**Worker group 3**
Threshold noise level	$L_{EX,\,1h}$ = 55 dB	$L_{EX,\,1h}$ = 70 dB	$L_{EX,\,8h}$ = 80 dB
Group characteristic	Workers requiring high levels of concentration or effortlessly communicate. Break rooms	Workers requiring concentration and/or the ability to communicate or workers who must be and/or be precise, react and/or be attentive	Workers not in group 1 and 2
Example of workers	Doctors, teachers, office workers, receptionists	Retail workers, warehouse workers, restaurants, ambulance workers	Heavy industry, carpenters, construction workers,

In Norway, it is also required that the noise measurements must be conducted by a professional, either an occupational hygienist or an acoustician in accordance with Norwegian standard NS 4815-1 or international standard ISO 9612. For worker refer to Table 1, the whole day must be measured, but only the noisiest hour will have to be compared to the regulatory threshold value, and consequently be below it. Also, noise caused by the employees own activity if the employee can stop the noise by themselves shall not be a part of the measurement [1][2].

When we conducted measurements according to this regulation, we had problems identifying noise sources in environments where noise levels were not significantly higher and noise abatement was not obvious. It was the case for when we conducted a noise measurement in a secretary's office. In an office with one employee and some through traffic of nurses, there was nothing to suspect to be an overwhelming noise source. Spending a half day, we finally figured out that the door slamming from the through traffic was the source of the noise. In addition to that, we had to remove the noise caused by the employee themself.

Another approach involves using sound recording or video cameras to identify the sound source. However, this method is not feasible in certain settings due to security concerns or the need to protect people's privacy. Similarly, this limitation applies to secretarial offices as mentioned earlier. Therefore, it's important to use another efficient method of identifying and estimating noise reduction without using such equipment would be useful for future noise exposure measurements. We therefore investigated the use of a time-difference-of-arrival directional device to infer the source of the noise. Since this device has been used outdoor but has not been used indoors, we conducted several experiments.

2. MEASUREMENT EQUIPMENT

In this measurement, a noise monitoring terminal Nor1545 developed by Norsonic was used to measure the noise level. A time-difference-of-arrival directional device "Noise compass" Nor1297 (TDADD) which is shown in Figure 1 was used to measure the direction of arrival of the noise sources [3]. TDADD is a measuring instrument that uses the cross-correlation method to identify the direction of arrival of noise sources. The cross-correlation method has been used in the past to measure the direction of arrival of construction site noise and aircraft noise [3][4]. These measuring instruments were used to simultaneously measure the noise level and the direction of arrival of the sound source, and to infer the noise source. Reverberation time measurements were also conducted to determine the conditions at the measurement site. Origami impulse source [5] invented by Kobayashi Institute of Physical Research was used to generate impact sound needed for the reverberation time measurements, and a precision sound level meter Nor145 was used for the reverberation time measurements. In pre-measurement test, we used power amplifier Nor282 and dodecahedron loud-speaker Nor283 to output white noise in each noise level.

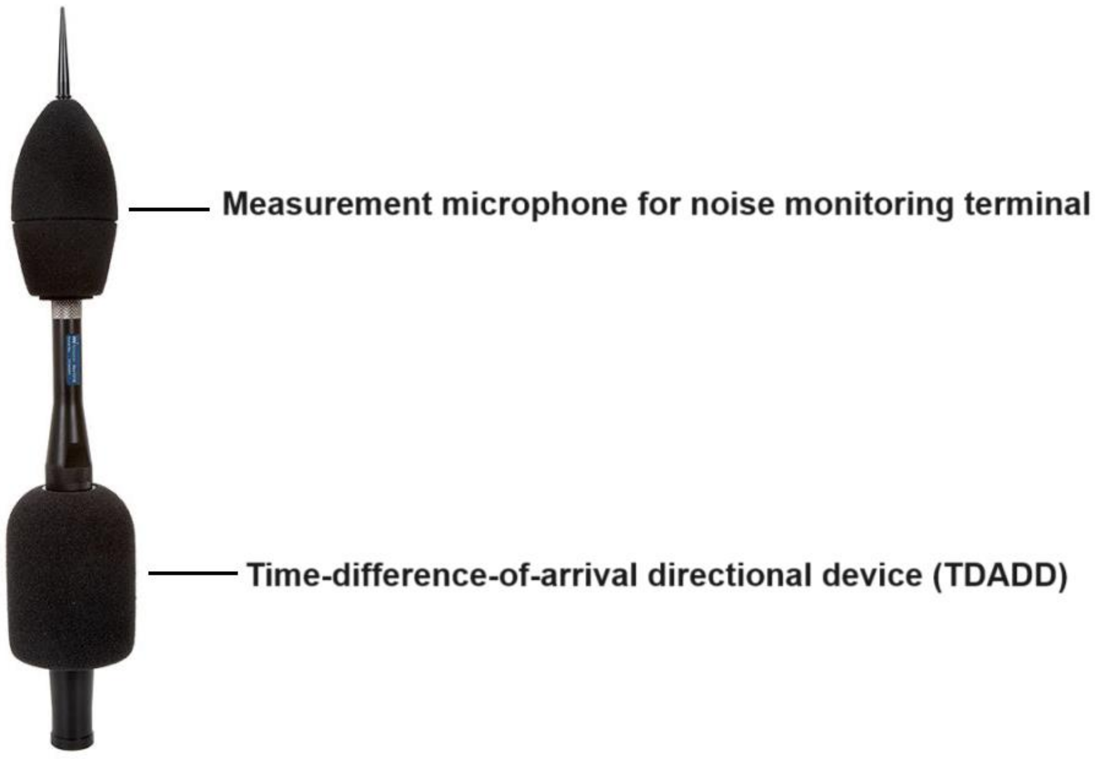

Figure 1: Measurement microphone for Nor1545 and Nor1297.

3. MEASUREMENT RESULTS

We conducted several types of measurements with the measuring instruments they are described in section 2. We performed preliminary measurements and then conducted measurements in Oslo University Hospital as the actual measurement site. This paper describes the results of the preliminary measurements and one of the measurement result under an actual site.

3.1. Pre-measurement in test room

First, measurements were conducted in a test room to verify the performance of TDADD in identifying the direction of arrival of noise sources in a room. The size of the test room is 6 meter * 10 meter. And there is no furniture in the room. As shown in the Figure 2 and 3, TDADD was placed in the center of the room and loudspeakers were placed every 90 degrees. White noise was output from the dodecahedron speaker for 10 seconds per measurement, and measurements were taken to see if TDADD could detect the direction of arrival. The background noise in the room was around 30 dB, and the white noise was set in 10 dB steps from 40 dB to 90 dB at the center of the room where TDADD was set up.

The measurement results are presented in Table 2. The reverberation time of the room was between 0.60 and 0.65 second. The results confirm that TDADD has the potential to identify the direction of arrival of noise sources indoors.

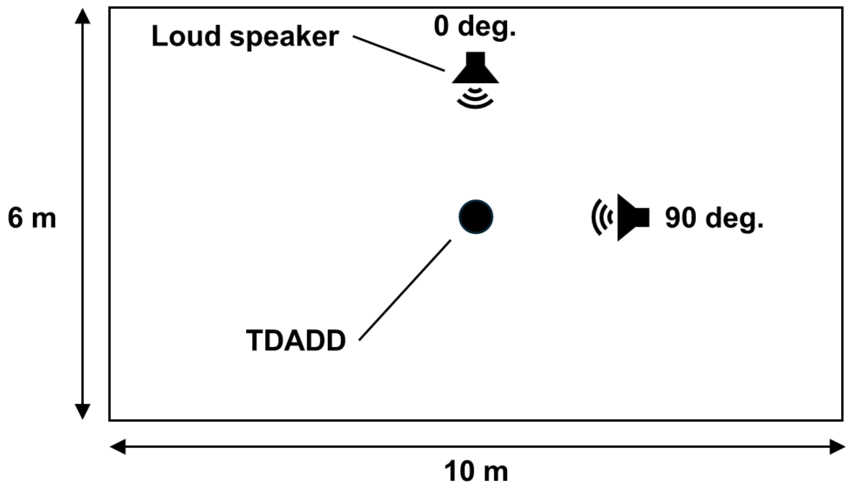

Figure 2: Floor plan of test rooms.

Figure 3: Pre-measurement landscape.

Table 2: Measurement results in test room.

Sound pressure level at center of the room	0 deg.	90 deg.
40 dB	✓	✓
50 dB	✓	✓
60 dB	✓	✓
70 dB	✓	✓
80 dB	✓	✓
90 dB	✓	✓

*✓ means TDADD can identify the sound direction.

3.2. Measurement in actual site

Based on the results of the pre-measurements we performed measurements in an actual room of similar room size and reverberation time. In the actual room, measurements were taken in a hallway in a building where extensive construction work was performed in part of the building. In addition to noise from the construction site in the building, the measurement point had a variety of sound sources present, including conversations from inside the secretary's office with the door open, the sound of automatic doors closing, and talking voices in the hallway. TDADD was placed at the position indicated in the figure 4. The top of TDADD was defined as 0 degree in this figure, and the noise level and the direction of arrival of the sound sources were measured. The size of the actual room(corridor) is 3 meter * 20 meter, and the reverberation time of the room was 0.50 to 0.55 second.

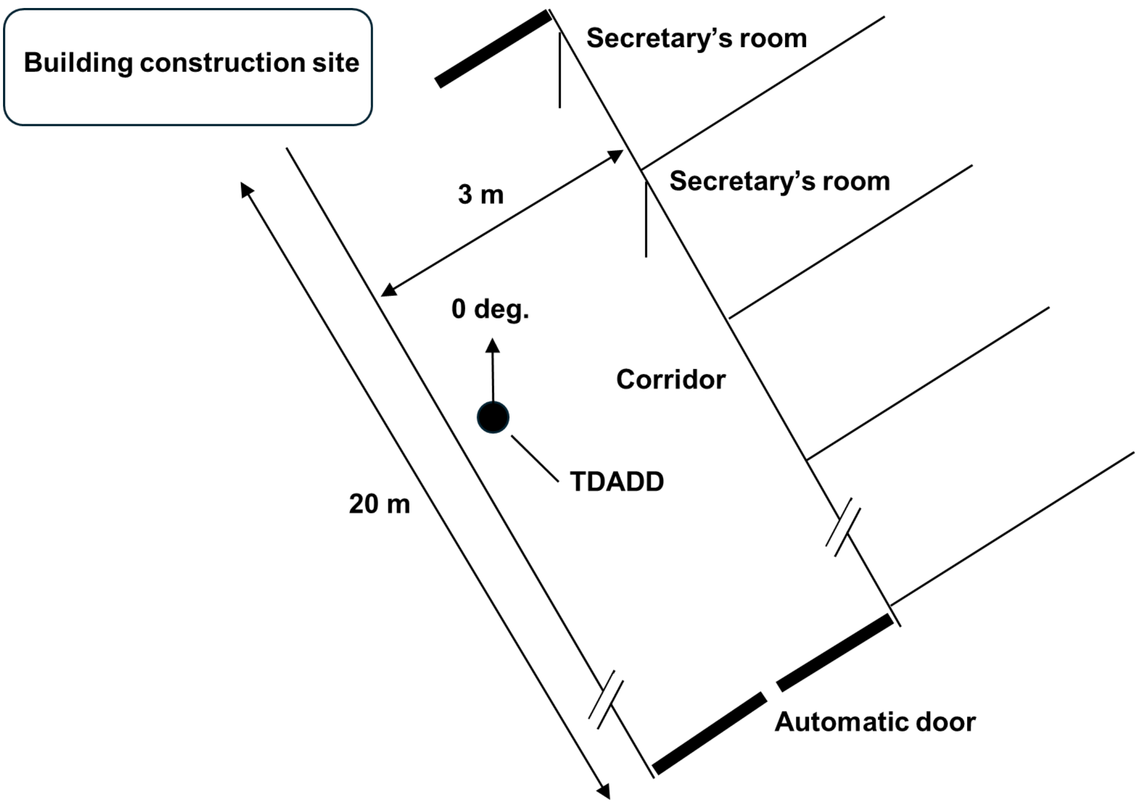

Figure 4: Floor plan of actual site.

The results of the measurements are shown in the Figure 5. This is a sampling of some of the measurement results. The top of Figure 5 shows the sound pressure level. The lower part shows the direction of sound arrival. For the data of the direction of sound arrival, only those with a correlation function of 0.6 or higher because of calculation by the cross-correlation method are shown. The noise coming from 0 to 30 degrees is assumed to be the conversation from the secretary's office, the noise coming from 120 to 150 degrees is the opening and closing of automatic doors, and the noise coming from 330 to 360(0) degrees is the noise from the construction work. We stayed in this room during the measurement and noted the noise source in our notes.

Figure 6 shows the measurement results. It should be noted, however, that this result does not remove values with correlation functions below 0.6. What should be noted in this result is the data in the vertical direction. In the horizontal direction between 45 and 90 degrees, the data was found to be below horizontal. This is assumed to be the result of reflected sound from the floor surface of the secretary's office conversation, or perhaps from sound emitted by people passing in the hallway.

The results of this measurement were compared to the contents of that note and were found to be consistent. By using TDADD, we were able to estimate the direction of arrival and the source of the noise, which could not be determined simply by looking at the sound pressure waveform. TDADD performs measurements continuously, and the results are automatically sent to a cloud server. The user can check the cloud server at any time to see the noise level and the direction of arrival of the sound source.

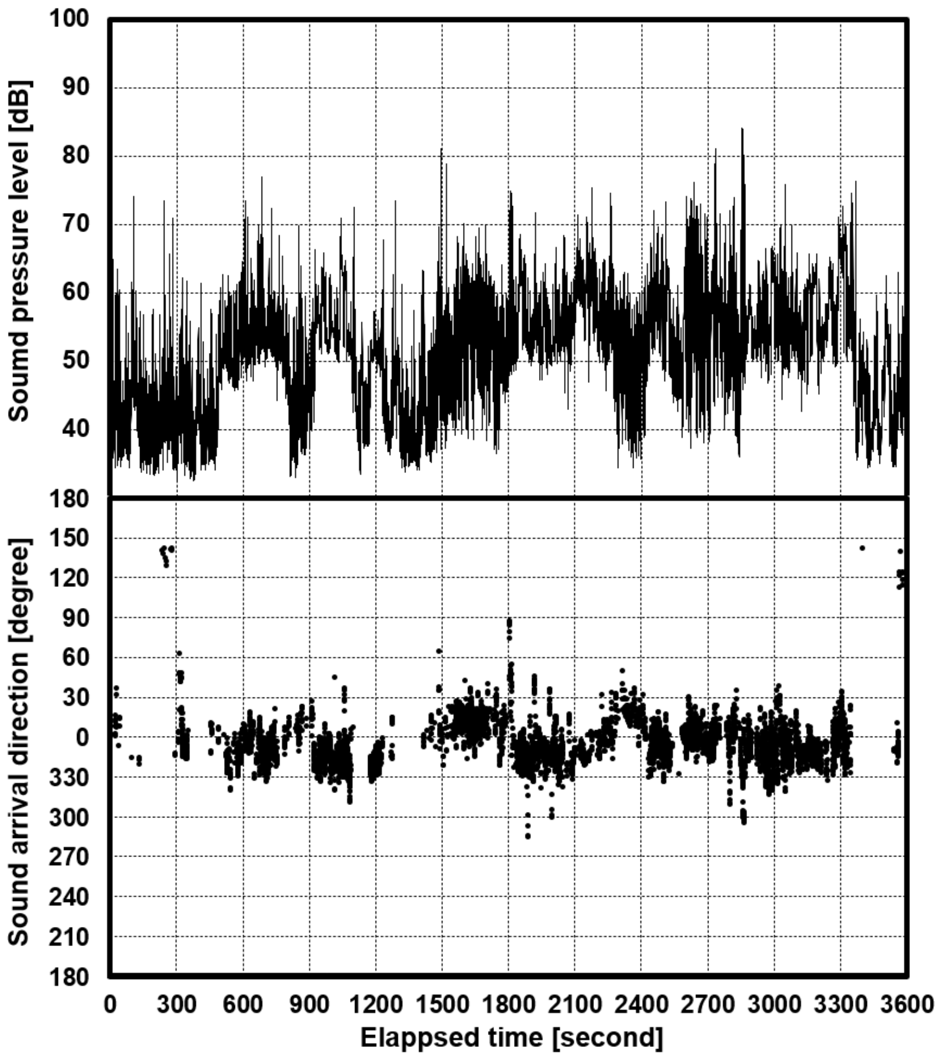

Figure 5: Measurement results - sound pressure level and sound arrival direction.

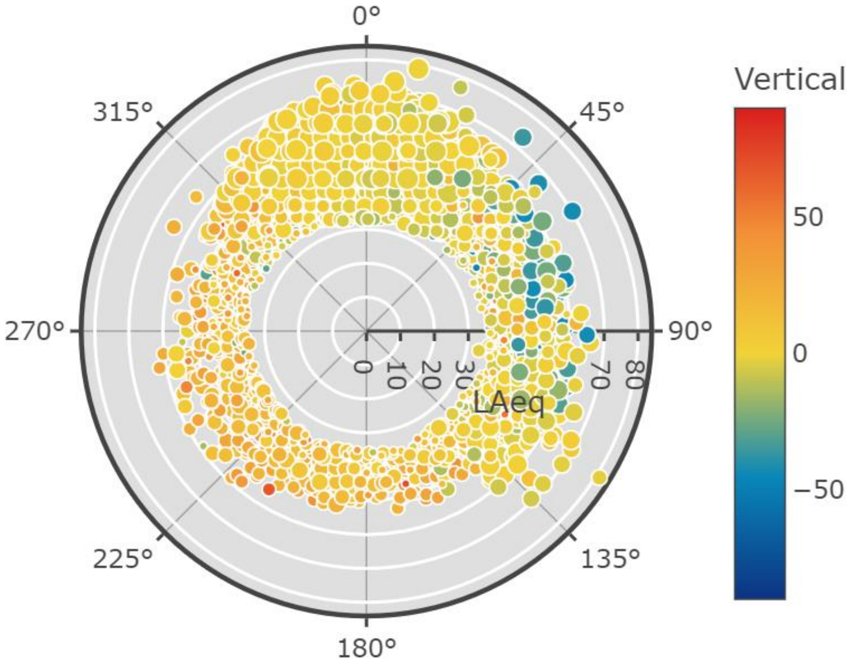

Figure 6: Measurement results – horizontal and vertical direction.

4. DISCUSSION AND FURTHER PLAN

The cross-correlation method used by the TDADD has limitations with respect to detection accuracy in reflective rooms. The accuracy is expected to be tightly coupled to the critical distance in the room. A more reverberant room will indeed reduce the accuracy, and the position of the TDADD in the room will influence the effect caused by reflective planes of the room. In the test rooms considered the reverberation time was measured from 0.5 to 0.6 seconds. Considering the dimensions of the test rooms, typical rooms such as offices, secretary rooms or meeting rooms with normal damping and acoustic properties seems to be suitable for directional detection. By carefully selecting the measurement position, the directional detection performed by TDADD may provide insightful data. We have not yet confirmed how small a room TDADD can be used in. In the future, the performance of the TDADD should be measured with respect to room volume.

In addition, for example, when used in a metal plant, it is possible to estimate the noise source and its noise level by taking measurements at several locations while the equipment of the noise source is running. The usefulness of TDADD in those environments also needs to be confirmed by actual measurements.

5. FINAL COMMENTS AND CONCLUSIONS

In noise measurements in occupational health, it is sometimes difficult to identify noise sources, and these are very time-consuming tasks. In this case, TDADD was used in the building to measure the direction of arrival of the noise source indoors. It was easy to measure the direction from which the noise was coming, even in a real measurement environment use case. In addition to that, the results can be easily available via our cloud system. It was suggested that work that previously needed half a day could be completed in a few minutes by simply checking the cloud server remotely.

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