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NOISE CONTROL FOR A BETTER ENVIRONMENT

Influence of engine noise in cabin on controlling the vehicle speed

Sukegawa Yoshiyuki[1]
Nishiwaki Shota[1]
Yoshida Junji[1]
Osaka Institute of Technology
5-16-1 Omiya, Asahi-Ku, Osaka 535-8585, Japan

ABSTRACT

Electric-powered vehicle (EV) have been popular in recent years. This transition makes interior noise more quiet by the reduction of the engine noise. On the other hand, the engine noise does not deteriorate only the sound quality in cabin, but the noise may have a role as the auditory information at driving. In this study, we then investigated an influence of the engine noise on controlling the vehicle speed through subjective test using a driving simulator. In the test, vehicle speed controlling task was given to the participants without speed meter at acceleration, deceleration and cruising conditions. As the presented sounds at these driving conditions, three conditions were prepared (1. IC condition with engine and background noise, 2. E condition with background noise, 3. S condition without any noise). As the result, the vehicle speed controlling ability was high in the IC condition especially at the acceleration and cruising conditions. Through the result, engine noise was clarified to make controlling vehicle speed easier and considering this characteristic for electric vehicle sound design was found to be important for safety driving.

Keywords: Vehicle interior noise, Engine noise, Speed controlling, Driving simulator
I-INCE Classification of Subject Number: 61, 63

1. BACKGROUND

In recent years, not only dynamic performance but fuel efficiency and ride comfortability of vehicles are also becoming important performance in vehicle development. The interior sound is one of the factors affecting the ride comfortability[1-6]. Concerning with the recent popularized electric-powered vehicle (EV), the radiated noise is generaly quieter than the conventional vehicle by the reduction of the engine noise. This phenomenon expects to improve the comfortability. On the other hand, the queiteness may decrease the auditory information of the vehicle to pedestrians and drivers. Hence, a lot of studies about vehicle approach alert sound have been carried out for the outside people[7-10]. However, the investigation of the influence of the engine noise reduction on the driver were rarely carried out[11].

[1] junji.yoshida@oit.ac.jp

In this study, we investigated the influence of engine noise as the information on the driver. Espessially, we focused on the vehicle speed controlling ability with or without the engine noise through subjective evaluation test using a driving simulator.

2. SPEED CONTROLLING TEST USING DRIVING SIMULATOR

2.1 Experiment outline

In this study, we carried out subjective evaluation tests in which participants controlled the vehicle speed when the engine noise existed or not at acceleration, deceleration and cruising by using simple vehicle driving simulator. In the test, the speed meter disappeared on the monitor and we obtained the deviation of the target speed and the actual speed in the simulator to evaluate the speed control ability.

2.2 Driving simulator

Figure 1 shows the driving simulator system employed in this study. The system was composed of simulator software, personal computer (PC), steering wheel, pedal, and head phone for replaying the vehicle sound.

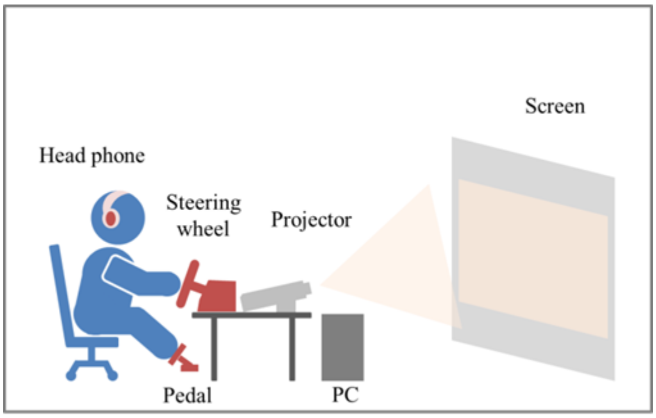


Fig. 1 Driving simulator system.

As the visual stimuli in the simulator, we did not prepare buildings and other vehicles except for a white dashed line on the road for the simple condition. About the auditory information at the driving condition, engine noise and background noise sources were prepared. The engine noise source was recorded in cabin of a conventional (engine) vehicle having four cylinder engine at the accelerating condition by using artificial head microphones (HEAD acoustics HSU 2). In the simulator, the level and frequency was adjusted according to the engine speed and load. In addition, the background noise was also recorded in cabin of the same vehicle when the vehicle was cruising at 100 km/h by the same system. Hence, the noise included the road and wind noise. The level was adjusted according to the vehicle speed. The reproduced level in the simulator at the 40 km/h in rapid acceleration condition and at the cruising condition at 80 km/h are shown in Fig. 2. The overall SPL of each condition was 58.4 and 63.6 dBA respectively, and the level was the almost same as the interior noise at the actual running condition of the test vehicle.

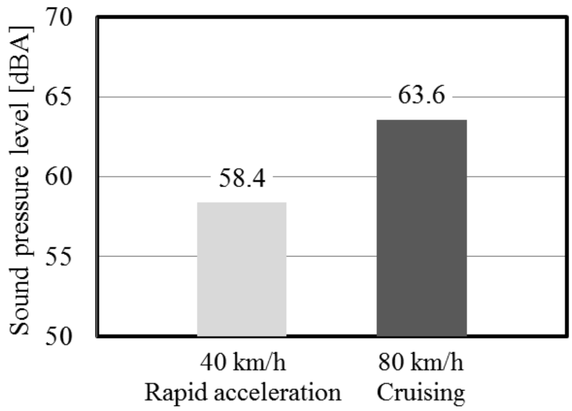


Fig. 2 The reproduced level in the simulator.

2.3 Speed control condition

The participants carried out the tests using driving simulator which was mentioned before. This simulator can be utilized at various driving conditions. In the test, the following three tasks were prepared.

Task 1) Speed control task at cruising condition.
Task 2) Speed control task to the target speed at acceleration condition.
Task 3) Speed control task to the target speed at deceleration condition.

Figure 3 shows the outline of the evaluation image at the cruising condition (Task 1). At first, the speed meter was displayed on the monitor for 35 s to get used to the relationship between the vehicle speed and the auditory-visual stimuli. After setting the vehicle speed at the target speed (40 or 80 km/h) using the meter, the meter disappeared from the monitor, and an instruction “Please keep the vehicle speed (40 or 80 km/h)” was given on the monitor for 45 s. And the participants attempted to keep the speed by adjusting the acceleration pedal according to the instruction without using the speed meter. During this task, the vehicle speed was recorded every 0.5 s for the analysis.

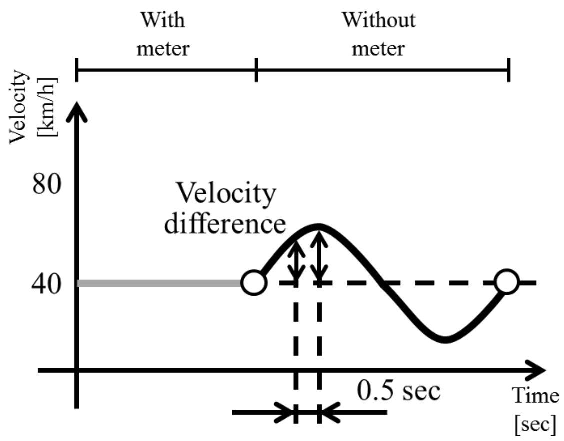


Fig. 3 Outline of the speed control task at cruising condition.

Figure 4 shows the outline of the evaluation image at acceleration condition (Task 2). In this task, the vehicle speed was firstly set at constant speed at 40 km/h using the speed mater. After then, the meter disappeared and an instruction “Please accelerate the vehicle to 80 km/h” was given. Then, the participant accelerated the vehicle by using the acceleration pedal and when he/she felt the speed reached at the target speed (80 km/h), he/she pushed a puddle shift button. The vehicle speed when the button was pushed was recorded to evaluate the speed control ability.

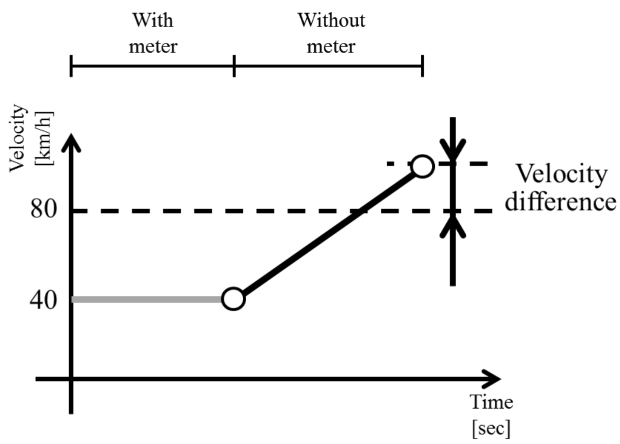


Fig. 4 Outline of the speed control task at acceleration condition.

Figure 5 shows the outline of the evaluation image at deceleration condition (Task 3). The vehicle speed was firstly set at constant speed at 80 km/h using the speed meter. After then, the meter disappeared and an instruction “Please decelerate the vehicle to 40 km/h” was given. Then, the participant decelerated the vehicle and when he/she felt the speed reached at the target speed (40 km/h), he/she pushed a puddle shift button as same as Task 2. The vehicle speed when the button was pushed was recorded to evaluate the speed control ability.

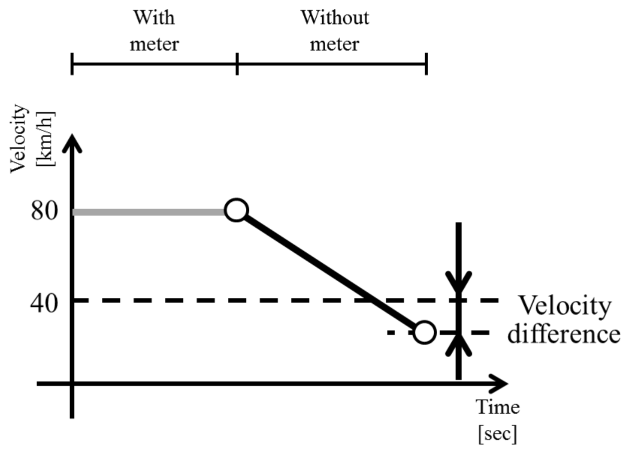


Fig. 5 Outline of the speed control task at deceleration condition.

In addition, for getting used to this subjective evaluation test and the usage of this driving simulator, accelerating and decelerating were performed in the simulator several times when the speed meter appeared on the monitor before the above mentioned tasks.

2.4 Auditory stimulus

For the investigation of the engine noise on the vehicle speed control using the driving simulator, three sound conditions were prepared. Table 1 shows the presented sound patterns in this test.

Table 1 Presented sound patterns.

Sound	Auditory stimuli	
	Engine noise	Background noise
IC	○	○
E	-	○
S	-	-

In this study, we focused on the vehicle speed controlling ability with or withour the engine noise. Hence, IC condition consisted of the engine noise and the background noise. We prepared this condition in case the participants drive the conventional vehicles having internal combustion engine. In the E condition, we prepared this condition when they drive electric vehicles. Accordingly, engine noise was not presented and they hear only the background noise. For the investigation of the interior noise, we prepared S condition in addition. In this condition, any interior noise was not presented and they control the vehicle speed using only the visual information. By comparing the vehicle speed control ablity among them, we analyzed the influence of the noise in cabin on the speed control ability.

2.5 Test procedure and participants

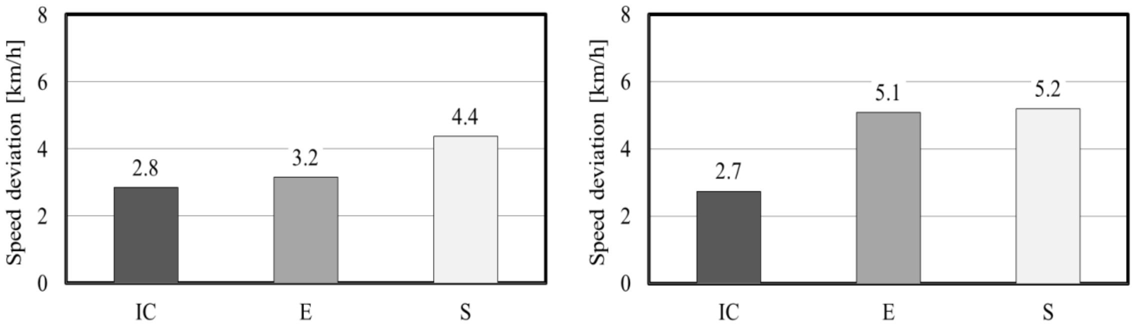
This experiment was carried out in the separated sessions. In each session, four tests consisting of Task 1 (40 and 80 km/h), Task 2 (acceleration), and Task 3 (deceleration) were performed two times. This session was repeated five times in total in each participant. Therefore, the speed control ability was evaluated in each sound condition in total five times in each driving condition.

About the participant, 24 Japanese male in 20’s participated. Twenty of them had driver licence. Accordingly 120 evaluations were carried out in each sound and condition in all participants.

3. EFFECT OF VEHICLE NOISE ON THE SPEED CONTROL

3.1. Constant speed controlling ability in cruising

At first, we analyzed the speed controlling ability at the cruising condition. In the analysis, we evaluated the speed difference between the target speed (40 or 80 km/h) and the actual speed in the simulator. In the subjective evaluation test, the vehicle speed was recorded in each 0.5 s for 60 s and the averaged speed was calculated using all recorded data in each condition and the participant. After then, the absolute deviation between the target speed and the averaged speed in the simulator was calculated. Figure 6 (a) and (b) shows the averaged speed deviation among all participants at 40 and 80 km/h, respectively.



(a) 40 km/h *(b) 80 km/h*

Fig. 6 Speed deviation between the target and actual speed in cruising.

As shown in the results, the speed deviation in the IC condition where the engine noise existed was observed to be the smallest in the three conditions and the deviation in the G condition was almost same as the deviation in the S condition when the speed was 80 km/h. The result indicates that even though we can keep the speed by setting the throttle pedal at the constant position, it was hard in the actual driving condition and the speed varied from the target speed. Furthermore, they are supposed to use the auditory information from the engine noise (frequency change of the engine order sound according to the speed) to keep the vehicle speed because the speed deviation in IC condition was smaller than the other conditions.

Figure 7 shows the comparison of the replayed sound from the simulator in IC and E conditions when the vehicle was cruising at 80 km/h. As shown in the figure, the engine order sound (pure tone component) could be observed clearly in IC condition on the contrary to the E condition. This information is considered to assist the speed keep task in this condition.

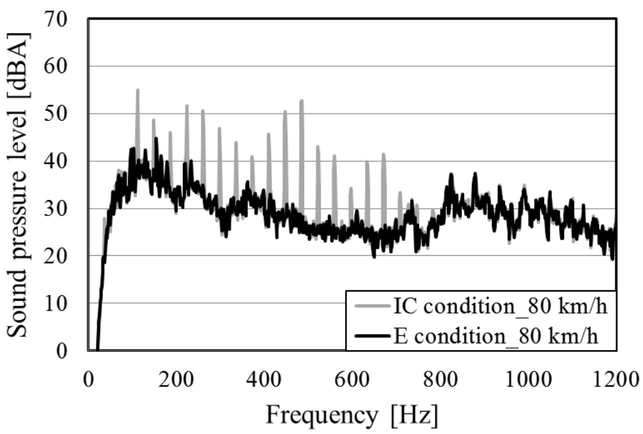


Fig. 7 Comparison of the interior noise at cruising of 80 km/h in IC and E conditions.

3.2. Speed controlling ability at acceleration condition

Here, we analyzed the result of the speed controlling test at the acceleration condition. In this test, we gave an acceleration task using the simulator in which the vehicle speed increased from 40 to 80 km/h without the speed meter. In the test, the participants pushed the paddle shift button when they felt the vehicle speed reached at 80 km/h after accelerating from 40 km/h. The actual vehicle speed when the button was pushed was recorded in each test. The absolute deviation from the target speed

(80 km/h) and the actual recorded was calculated as the speed deviation. Figure 8 shows the averaged deviation at the acceleration condition among all participants.

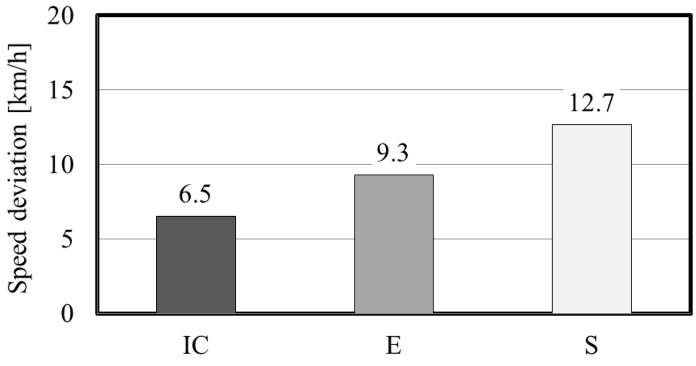


Fig. 8 Speed deviation at the acceleration condition.

As shown in the upper figure, the speed deviation of IC condition was significantly smaller than that of E and S conditions as same as the cruising condition. The deviation of IC condition is around two times smaller than S condition. From the results, the participants were found to use the auditory information of the vehicle in the acceleration condition for controlling the vehicle speed, and the engine order sound seems to be informative signal to estimate the speed. For the verification of the consideration, we compared the spectrum of acceleration noise of IC and E conditions at 40 and 80 km/h in Fig. 9 and Fig. 10 respectively.

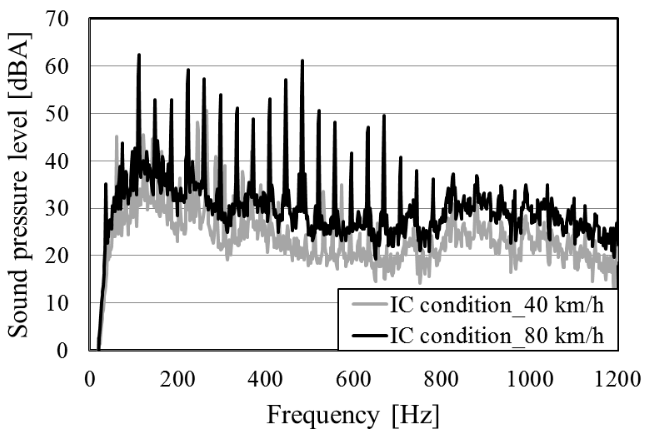


Fig. 9 Comparison of the interior noise of IC conditions between 40 and 80 km/h at acceleration condition.

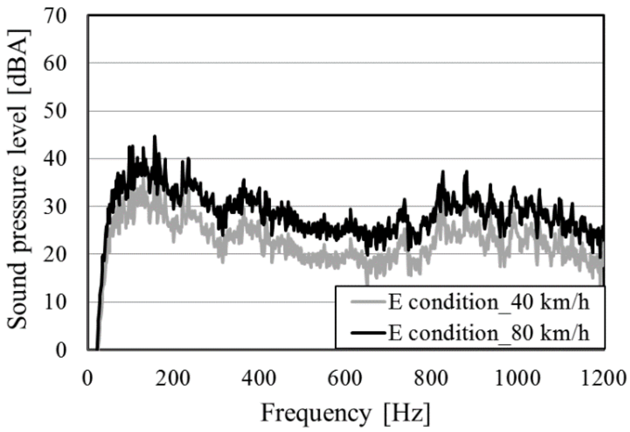


Fig. 10 Comparison of the interior noise of E conditions between 40 and 80 km/h at acceleration condition.

From the figure, not only the level difference between them but the frequency of the engine order sound was also observed to change clearly in IC condition. On the other hand, in the E condition, the frequency change was hard to see and the level difference was only observed according to the change of the speed. Therefore, the speed deviation in IC condition was considered to be much smaller by using the frequency change as same as the cruising condition.

Through the subjective evaluation at cruising and acceleration conditions, we could find the change of the frequency has an important role for controlling the vehicle speed accurately.

3.3. Speed controlling ability at deceleration condition

At last, we analyzed the subjective evaluation results at the deceleration condition. In this condition, we calculated the speed deviation between the target speed (40 km/h) and the actual vehicle speed when the participant pushed the paddle shift button from the deceleration at 80 km/h as the same manner as the acceleration condition. The averaged speed deviation among all participants in each condition was shown in Fig. 11.

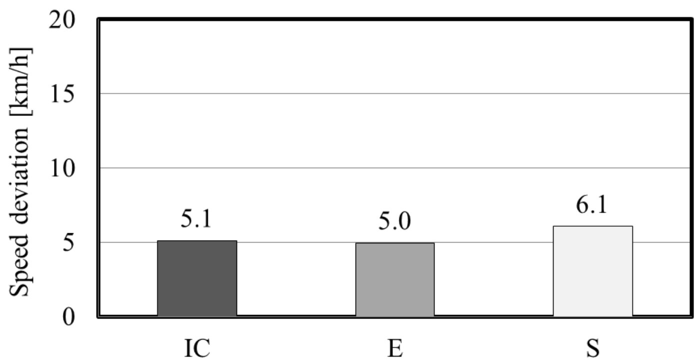


Fig. 11 Speed deviation at the deceleration condition.

As shown in Fig. 11, the speed deviation of the IC conditions was about 5 km/h and the deviation was almost same as that of the E condition contrary to the result at cruising and acceleration conditions. This indicates that the engine noise did not assist the estimation of vehicle speed only at the deceleration condition. For the discussion of the exceptional result, the interior noise of IC and E conditions at 80 km/h and 40 km/h are compared in Fig. 12 and 13, respectively.

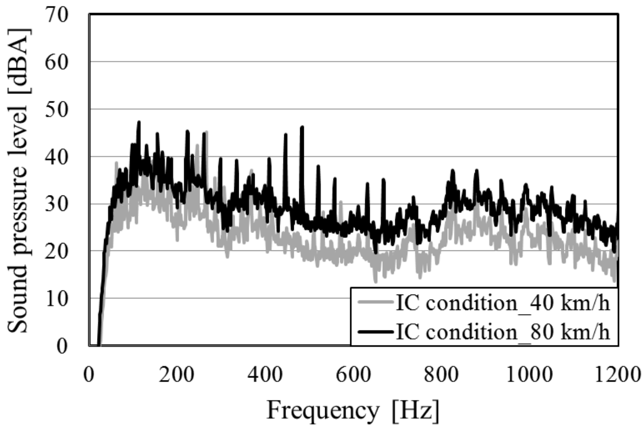


Fig. 12 Comparison of the interior noise of IC conditions between 80 and 40 km/h at deceleration condition.

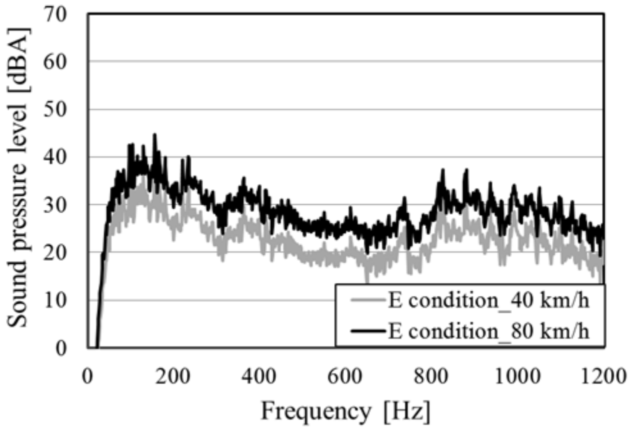


Fig. 13 Comparison of the interior noise of E conditions between 80 and 40 km/h at deceleration condition.

As shown in the upper figures, the frequency change before and after deceleration was small both in IC and E conditions. Because the throttle pedal was generally not used in the deceleration condition and the engine order noise became very small on the contrary to the acceleration situation in IC conditions (Fig. 8). Accordingly, the participants could not use the engine noise (frequency change of pure tone component) for controlling the vehicle speed at this condition. From the result, we again confirmed the frequency change by the engine noise becomes important information for controlling the vehicle speed as the auditory information and the effect becomes significant especially at cruising and accelerating conditions.

4. SUMMARY

In this study, we carried out a subjective evaluation test using a driving simulator to investigate the effect of the vehicle interior noise on the speed controlling ability at cruising, accelerating and decelerating situation. In the test, three auditory-visual conditions were prepared. IC condition consisted of engine and background noise with the visual stimuli, E condition had background noise and the same visual stimuli and S condition did not include any auditory information but the identical visual stimuli.

The speed control task was then prepared for the participants and they attempted to control the speed without speed meter in each situation. As the result, the participants were found to use the engine noise information to control the vehicle speed well. Especially the frequency change of the engine order noise took an important role to estimate the speed well. Therefore, this phenomenon was observed at the cruising and acceleration situation mainly. On the other hand, not only the presence of the auditory information from the vehicle, but realizing comfortable sound quality is also important to realize optimized auditory environment in EV cabin. Hence investigation of the suitable sound considering the both characteristics is necessary in future work.

5. REFERENCE

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