Robustness Against Hazard Notifications Around a Vehicle Using Seat Actuators

Akimasa Suzuki
and Yoshitoshi Murata
Department of Information Science,
Iwate Prefectural University
020-0693, Sugo, Japan
suzuki_a@iwate-pu.ac.jp

Shoma Fujimura
Ad-Sol Nissin Corporation,
Kawasaki-shi, 210-0804,
Kanagawa, Japan
oaurn85ns@outlook.jp

Abstract—**This paper examines the robustness of our proposed haptic notification system against the different types and layers used for driving seat cushions. While many car manufacturers provide useful side and rear collision warning systems with sound alarms or visual monitors, the addition of similar notifications can confuse a driver because they already need to be aware of many visual targets such as mirrors, monitors, and environmental sounds. Therefore, we have investigated a haptic notification system that uses the driver's buttocks. The results show that drivers can correctly identify the directions of five vibrating motors, three intensity settings, and three obstacle types (*i.e.*, pedestrians, vehicles, and motorcycles). In this paper, we investigate whether drivers can discriminate the direction, intensity of vibrations, and vibration patterns of the system through their buttocks to identify the obstacle direction, degree of risk, and the type of obstacle, even if the vibrations are attenuated by the seat cushion. The results indicate the high potential of the haptic sensation system to notify the driver of obstacles, especially those located in the blind spot.**

Keywords-Vibro-Tactile Notification; Type of Obstacle; Buttocks; Acoustic Haptic Actuators; Seat Cushion.

I. INTRODUCTION

There has been considerable research in investigating accident prevention systems for vehicles, particularly in relation to developing driving support systems that will transition to autonomous driving systems. However, to realize autonomous driving systems, we must overcome problems related to cyber-security measures and traffic laws (*e.g.*, responsibility for accidents by autonomous cars [1]), which could take time. Additionally, as many people enjoy driving, the demand for manual driving as a hobby is unlikely to fade. Driving support systems will thus remain an important feature. Moreover, despite the high number of driving support systems used in Japan, many fatal vehicle accidents are caused by violations of safe driving practices, such as failing to keep eyes on the road, careless driving, and failing to make safety checks [2], thus highlighting the need to develop more techniques that support drivers.

To develop a support system that helps drivers to avoid vehicle accidents, the system needs to quickly and accurately sense information and notify the driver so that he/she can make a rapid judgement. Most car manufacturers now install highly accurate sensor systems at the front and rear of their vehicles at a low cost. Support systems located at the front of a vehicle use vision [3] or radar [4] sensors to prevent careless driving and overcome a driver's failure to make safety checks, while support systems located at the rear of a vehicle use sensors and notification systems to monitor a driver's rear view and blind spot [5]. These systems use sound or visual images to alert drivers to potential hazards.

Visual images can quickly notify a driver about many kinds of information using shapes and colors. As vision is the dominant human sense [6], many notifications rely on the driver's vision, including the front view, mirror, tachometer, speedometer, navigation system, and indicators. There is a concern, therefore, that excessive visual information could affect a driver's capacity to adhere to safe driving practices [2]. We thus consider that developing an additional visual notification may cause the driver to confuse it with conventional visual notifications.

Many conventional systems also provide information to drivers in the form of sounds (*e.g.*, alerts by horn; car audio, including radio; and alarms for reverse gear, pre-collision, and lane departure). Directions presented by a satellite navigation system are also expressed through the vehicle's stereo system. To avoid confusing the driver, we considered creating different sounds, pitches, and patterns for each type of obstacle; however, these would not be intuitive. Additionally, notifying a driver using speech would be too slow to get communicate the message in time. It is also difficult to apply a system using sound on a late-night bus travelling long distances because sleeping passengers may get up by the alert.

Therefore, we proposed a system that uses haptic sensations to quickly notify drivers of possible hazards or obstacles surrounding the vehicle [7]. Our proposed system has higher immediacy and directional resolution than notifications using sounds. As no driver notification system currently uses haptic sensations, we do not have to consider conflicts in this area. Our proposed notification system uses vibro-tactile haptic devices that remain in constant contact with the driver's buttocks. We evaluated the system's robustness against cushion type for determining the direction and intensity of vibrations and road conditions. A high intensity expresses the extent of the danger and the direction of the vibration indicates the location of the hazard. The system can also alert the driver to different types of obstacles, such as a pedestrian, car, or bike. The results indicated a high potential for notifying drivers of obstacles, especially those located in the blind spot.

To support safe car driving, our proposed haptic notification system installing vibration alerts into a driving seat. This paper examines its robustness against different types and layers used for driving seat cushions.

The remainder of the paper is structured as follows. Section II discusses relevant studies, Section III describes the proposed system, Section IV describes the modulated waveforms generated for precise notification, Section V presents the experiments to test the robustness of the system, and Section VI presents our conclusions.

II. Relevant Studies

Many practical driving support systems apply image sensors [3], radar [4], and ultrasonic sensors [8] to detect pedestrians and other vehicles with high accuracy. Around-view monitors are increasingly being used for automatic parking [9] and lane-detection systems are being applied using three-dimensional (3-D) laser imaging detection and ranging (LIDAR) [10]. Despite their weakness to other noise sound, ultrasonic sensors can now be installed in driving support systems for a low cost, while the cost of 3-D LIDAR is also dropping. These devices can be used to detect not only the presence of an obstacle, but also the type of obstacle (*e.g.*, pedestrian, vehicle, or motorcycle). However, in this research, we focus on creating a notification method to alert drivers to the potential hazards, rather than the development of a sensor system.

Previous research on evaluating seat comfort has demonstrated that buttocks are sensitive to tactile sensations [11]. Although not used in the driving seat, some studies have reported the effectiveness of vibro-tactile devices for notifying drivers of directions when using a wearable device such as a belt [12]. The directions of obstacles could be detected by using vibro-tactile devices on the seatback [13] because the back is more sensitive than the buttocks; however, as drivers need to lean against the backrest, the system might have a negative effect on the driver's posture. A vehicle notification device using vibro-tactile devices on the buttocks was therefore developed [14], although the system was unable to indicate the direction of a hazard to the driver.

In a gaming device, vibro-tactile devices are used to link a virtual object with reality [15]. Therefore, we consider applying a vibro-tactile device to notify the driver of essential information related to potential hazards based on the intensity and direction of vibrations. Tactile sensations can include rubbing, pain, pressure, and warmth. On the streets, tapping on the shoulder is a popular method for pedestrians to alert each other. To our knowledge, this study is the first to notify a driver of information such as the direction of a hazard in relation to the vehicle, the extent of the urgency based on the intensity of the vibration, and the type of hazard by the vibration pattern expressed using vibro-tactile devices located below the buttocks.

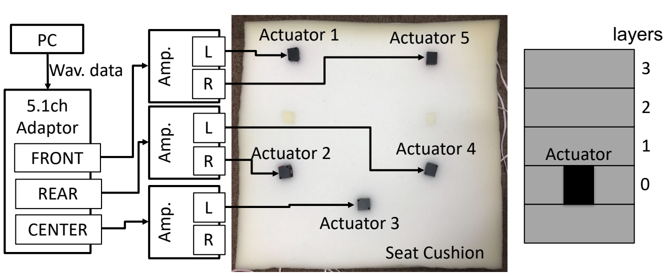

Figure 1. Hardware layout of the notification system using an ACOUSTICHAPTIC™ actuator.

III. Vibro-tactile Notification System Around a Vehicle Using Seat Actuators

We will indicate our proposed vibro-tactile notification system in this section.

A. System Architecture

For our proposed system, we utilized a vibrating motor with an ACOUSTICHAPTIC™ actuator developed by Foster Electric Company Limited. The acoustic haptic actuator is a kind of woofer that comes into direct contact with the driver's buttocks. Fig. 1 shows the hardware layout for this system. The edited waves were played on a PC, and the five actuators vibrated on the seat, as shown in Fig. 1. These actuators contact with the back of the driver's knees. We used the AP05 amplifier produced by Fostex.

In this experiment, we administered four vibrating patterns of the same intensity, representing different obstacle types, to fifteen participants. The participants were asked to identify the type of obstacle from the vibration pattern. We conducted five trials in a random order for each participant. The vibrations included the sound of footsteps from leather shoes [16], the sound of a V6 engine revving up [17], the sound of a bus driving uphill [18], an idling sound [19] as obstacle types of pedestrian, small and large four-wheeled vehicles, and a motorcycle, respectively. We hypothesized that drivers would intuitively recognize the type from the vibration pattern of the real sound.

As shown in Fig. 1, up to three layers of urethane cushions were placed over the actuator to evaluate the robustness. The thickness of each layer is 2 cm. We also define "layer 0" to mean that nothing is placed over the actuators. We utilize three types of urethane cushion, with specifications shown in Table 1. We defined 20 ss, 35 s, and BZ-10 constructed by Toyo Quality One as soft, highly resilient, and less resilient cushions, respectively, as shown in Table 1.

We generated vibration waveforms from these sound data, to decreasing up to 2 kHz and increasing between 55 Hz and 110 Hz, which are resonance frequencies of the ACOUSTICHAPTIC™ actuator. Fig. 2 shows the waveforms of these four vibrating patterns, *i.e.*, (a) a pedestrian, (b) a

TABLE I. CUSHION MATERIALS FOR EVALUATION.

	Soft	**Highly Resilient**	**Less Resilient**
Constructor	Toyo Quality One	Toyo Quality One	Toyo Quality One
Product name	20 ss	35 s	BZ-10
Density ($\mathrm{kg/m^3}$)	20 ± 2	55 ± 2	35 ± 3
Hardness (N)	30 ± 15	45 ± 15	60 ± 15
Tensile intensity (kPa)	$50 \leq$	$60 \leq$	$30 \leq$
Elongation (%)	$200 \leq$	$100 \leq$	$80 \leq$
Tensile intensity (N/cm)	$3.0 \leq$	$2.0 \leq$	$2.0 \leq$
Compressive residual strain (%)	$10 \geq$	$12 \geq$	$15 \geq$

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motorcycle, (c) a small 4-wheel vehicle, and (d) a large 4-wheel vehicle. The horizontal and vertical axes indicate the time and amplitude, respectively. A waveform of the pulse vibration with a walking frequency of 0.4-s intervals was used for the pedestrian. We applied the 55-Hz and 110-Hz resonance frequencies to large and small four-wheeled vehicles, respectively. The amplitude of the waveforms was normalized because we utilized the different amplitudes (*i.e.*, the intensity of the vibration) to express the urgency of the degree of risk or the distance to the obstacles.

B. *Abilities of the Proposed Notification Systems*

A study of our proposed conventional system proved it to be effective [7]. However, the vibrating motor used in our conventional system was unable to assign different vibration patterns to different obstacle types. Fig. 3 shows the correct answer rates for (a) the direction, (b) vibration intensity, and (c) both direction and intensity using the vibrating motor. When participants took longer than 5 s to respond, measured using a stopwatch, we considered it to be too slow and treated their answer as incorrect. In the correct answers shown in Fig. 3, the response times of all trials indicate that drivers could understand the information of the surrounding obstacles in less than 1 s. The correct answer rates for direction, intensity, and both direction and intensity in all route types were 84.4%, 72.6%, and 62.2%, respectively [7].

Fig. 3(a) shows that the drivers produced the highest number of correct answers when driving on the winding local road, followed by the arterials and the collector roads; however, as Fig. 3 (b) shows, the accuracy of the drivers' responses for the intensity were in the reverse order. This difference is likely because the vehicle's vibrations when travelling at low speeds could confuse the driver. The pressure between the vibrating motor and the buttocks could also change during the trials because the driver had to constantly control the accelerator and brake on the winding road. Nevertheless, the participants were able to determine the direction and intensity of over 50% of the vibrations when driving on the proposed seat.

For determining obstacle types, we applied the ACOUSTICHAPTIC™ actuator. Figs. 4 and 5 indicate the correct answer rates for the four types of obstacles. The graph

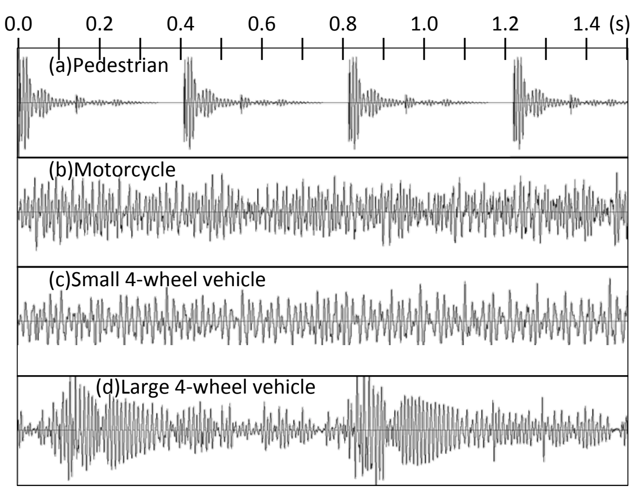

Figure 2. Waveforms of the vibrations for the four obstacle types.

also shows the rate for each trial by type. The vertical and horizontal axes in Figs. 4 and 5 show respectively the correct answer rate and vibration type of the waveforms shown in Fig. 2. Fig. 4 presents the correct answer rates based on the waveforms of the four obstacles types. As Fig. 4 shows, the correct answer rates improved during the trial, except for those for the four-wheeled vehicle (small). All participants were able to identify the pedestrian and motorcycle vibrations; however, they could only identify 50% of the other types of vibrations because the vibration patterns were too similar for them to sense the differences. However, after combining the large and small four-wheeled vehicles, the participants could detect the three patterns with high accuracy. Fig. 5 shows the results for three obstacle types, integrating the large and small four-wheeled vehicles. The correct answer rate reached over 90% at the fifth trial, as shown in Fig. 5.

IV. Modulation for Precise Notification

From the waveforms shown in Fig. 2, we generated modulated waves for precise notification. We determined the waves with a frequency an octave lower than the original wave as the modulated waves for more clearly feeling the differences of vibration. Figs. 6(a) and (b) show spectra of the original and modulated waves for large four-wheeled vehicles. The horizontal and vertical axes indicate the frequency and power spectrum, respectively. The spectra of the modulated waves consist of sine waves under 1 kHz.

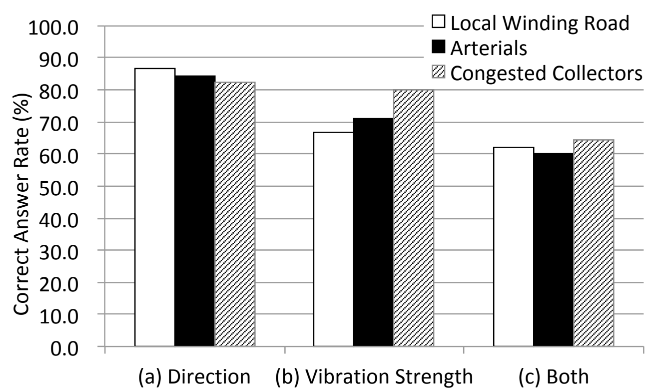

Figure 3. Correct answer rates on local winding roads, arterials, and congested collectors.

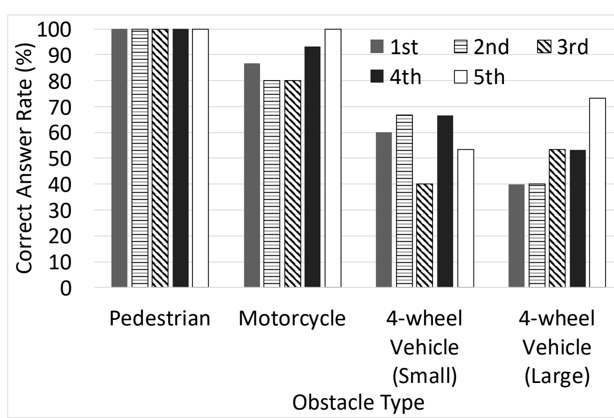

Figure 4. Correct answer rates for notification using haptic actuators.

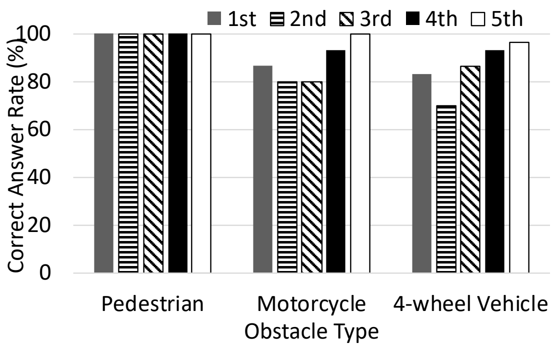

Figure 5 Correct answer rate for obstacle type notification on three obstacle types

For the intensity expression, we utilized three intensity waves, as shown in Table 2, which shows three vibrating volumes corresponding to three steps of intensity (*e.g.*, small, medium, and large). We applied 8 dB intervals between the three steps, and we prepared the signals with the three steps of volume on each modulated waveform for the three obstacle types: pedestrians, motorcycles, and four-wheel vehicles.

V. Experiments for Robustness Against Cushion Type

We evaluated the robustness against cushion type in a near-practical environment. As shown in Fig. 1, we mounted a vibrating car seat on a test vehicle for evaluation by five test drivers with considerable driving experience. The test drivers reported the vibration intensity, direction, and obstacle type when they sensed the vibration. Before the evaluation, the test drivers felt nine types of vibrations (*i.e.*, three intensities for the three obstacle types) at each actuator, shown as Actuator 1 to Actuator 5 in Fig. 1. The bold line in Fig. 7 indicates the experimental route. The actuator is vibrated at random times while the test drivers drive on a circuit track, shown in Fig. 7, at speeds of less than 20 km/s. Answers were only considered valid when received within 5 s of the vibration.

TABLE II. SOUND VOLUME CORRESPONDING TO THREE STEPS OF VIBRATION INTENSITY.

	Volume (dB)
Small	−16
Medium	−8
Large	0

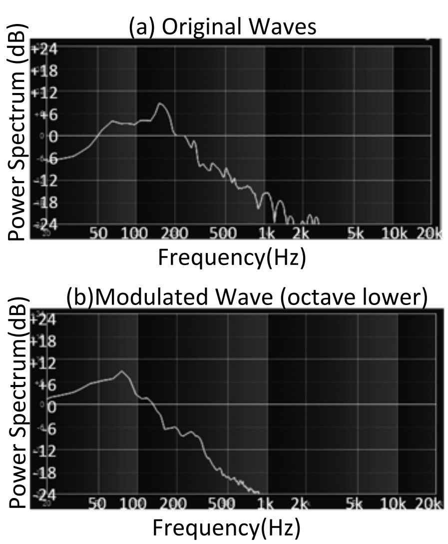

Figure 6. Sound spectra for 4-wheeled vehicles (a) before and (b) after modulation.

Figure 7. Route for the driving experiment.

A. Experimental Results

Fig. 8 shows the average ratings for comfort of each seat layer and material. The vertical and horizontal axes represent the average comfort rating and the cushion layer and material, respectively. The ratings were ranked according to the softness and resilience (high or low) of the seat cushion up to several layers. The test drivers tended to evaluate the seat based on whether they were conscious of the actuators.

The experimental results indicate the importance of retaining a high notification ability in a thick cushion even though a synthetic judgment is required for other evaluations, such as ease of driving.

Figs. 9 to 12 show the results for robustness against cushion type and present the correct answer rates as relative values based on a correct answer rate for layer 0. The vertical and horizontal axes present the correct answer rate and cushion layer and material, respectively. Figs. 10 to 12 also present the standard deviations for all answers.

Fig. 9 shows the differences between the correct answer rates for the intensity, direction, and obstacle types between

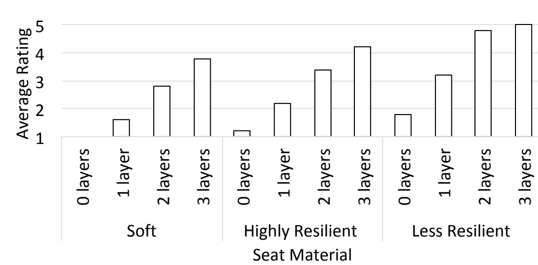

Figure 8. Comfort ratings for each seat layer and material.

layer 0 and the other layers. The results show that the correct answers for the highly resilient cushion decrease as the layers increase; however, the other cushion materials maintain robustness even with an increased cushion thickness.

B. *Intensity Expression*

Fig. 10 shows the average differences in the correct answer rates calculated from the answers relating to the intensity of the vibrations (*e.g.*, small, medium, or large, as shown in Table 2). The more layers the seat cushion has, the more the correct answer rates decrease, except for the less resilient cushion. A high standard deviation is obtained for the results of the less resilient cushion, although the trend of the correct answer rates for the layers is different. Therefore, it cannot be said that the number of correct answers will increase for more layers in the less resilient cushion.

C. *Direction Expression*

Fig. 11 shows the average differences in the correct answer rates, which are calculated from only the answers relating to direction (*e.g.*, left corresponding to Actuator 1 and right corresponding to Actuator 5, shown in Fig. 1). In this experiment, the test drivers gave the direction by stating “right”, “right back”, “back”, “left back”, or “left” when they noticed the vibration. The results shown in Fig. 11 confirm substantial differences between the different seat cushions.

D. *Obstacle Type Expression*

Fig. 12 shows the average differences in the correct answer rates calculated from the answers relating to the obstacle types (*e.g.*, pedestrians, motorcycles, or four-wheeled vehicles, shown in Fig. 5). The more layers there are, the more the correct answers decrease, except for the soft cushion. In the case of the soft type with 0 layers, it was difficult to judge when the actuators made direct contact with the buttocks based on the features of the waveform because the soft type of seat sank more easily than the other types. As a result, the correct answer rates on the soft cushion could be increased.

Based on the results shown in Figs. 9 to 12, the total correct answer rates are strongly influenced by the intensity of the vibrations; thus, the robustness is demonstrated without to the intensity steps of the vibrations.

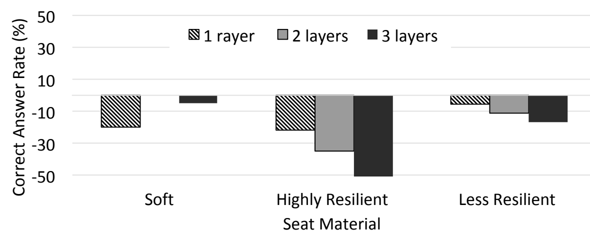

Figure 9. Correct answer rates for each seat material.

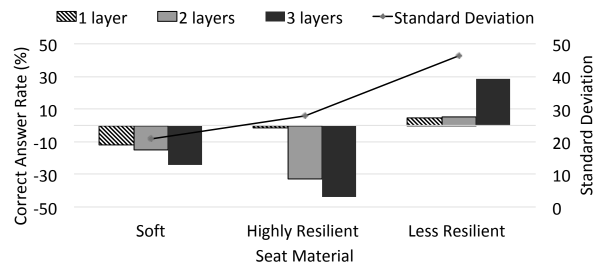

Figure 10. Correct answer rates for intensity for each seat material.

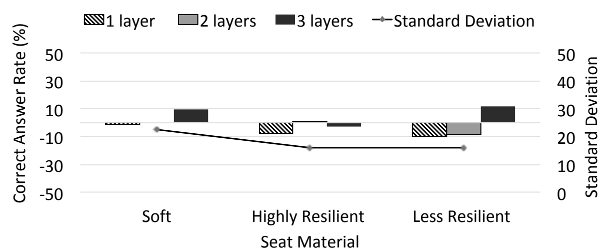

Figure 11. Correct answer rates for direction for each seat material.

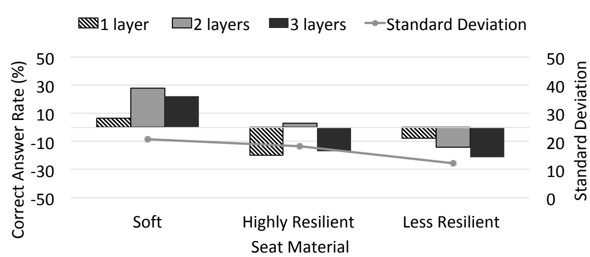

Figure 12. Correct answer rates for obstacle type for each seat material.

VI. CONCLUSION

We examined the robustness of a vibro-tactile device by collaborating with a car manufacturer to install acoustic haptic actuators into the seat cushion of an actual automotive vehicle.

We proposed a vibro-tactile notification system using vibrating motors to notify drivers of hazards around a vehicle, which were sensed using conventional sensors. The effectiveness of this method was evaluated from the viewpoint of resolution of intensity and direction and robustness against cushion type for determining the road conditions. The vibration pattern also enabled drivers to recognize the type of hazard, such as an approaching pedestrian or motorcycle.

We conducted several experiments involving driving on public roads in a car with seven vibrating motors installed under the driver’s seat. By applying acoustic haptic actuators as a vibro-tactile device, test drivers could detect three types of vibrating patterns, indicating different types of obstacles: pedestrians, motorbikes, and four-wheeled vehicles. We also determined that drivers’ recognition of the intensity, direction, and hazard type could be improved over time because they could learn from experiencing the vibration alerts.

The results indicated the high potential of using a haptic sensation device to notify drivers of obstacles in their blind spots by creating a vibration against the buttocks. The experimental results, shown in Fig. 9 to 12, illuminated that the intensity of the vibration, which should indicate the level of the hazard, could not be considered in the robustness test. By reconfiguring the intensity, as shown in Table 2, the robustness could be improved, which we will investigate in future work.

The proposed system is expected to reduce accidents by notifying drivers of other drivers and obstacles. In future works, we will conduct these experiments using more test drivers to compare elderly people with very young people or to observe its effectiveness with truck drivers and people with different levels of attention or tiredness. We will also evaluate the operational difficulties of the system in case of an emergency. We will also corroborate the visual and audio notifications of our system and examine the effectiveness for making quick driving decisions with intuitive notifications.

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