Vibro-tactile Notification in Different Environments for Motorcyclists

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Abstract—**This paper evaluates the effectiveness of vibro-tactile notification for motorcyclists under external factors. Although many car manufacturers provide side and rear collision warning systems with auditory or visual alarms, the notifications may confuse a motorcyclist because they already need to be aware of many visual targets such as mirrors and monitors, and environmental sounds. This paper proposes vibro-tactile notification system using a vibration speaker installed in a motorcycle helmet between the outer shell and the cushion. The proposed system should enable motorcyclists to correctly identify the directions of five vibrating motors, three level of risk, and three obstacle types (i.e., pedestrians, vehicles, and motorcycles). We evaluate the system under windy and engine vibration conditions and examine accuracy of notification via experiment. Our results indicate that motorcyclists can correctly detect four directions and three threat levels using this system.**

Keywords–vibro-tactile notifications; helmet actuators; vibration speakers;

I. INTRODUCTION

Because once the motorcyclist is in a crash, they are more likely to die as a result of less protection from the vehicle. For motorcyclists, hazard notification is vital, because of their limited visibility and the diverse sounds they may hear and their very high risk of accident. The fatality rate in crashes for motorcyclists is 1.22% , while that for drivers of four-wheeled vehicles is 0.35% [1] . Furthermore, motorcycles are small and difficult for other drivers to recognize. Motorcyclists therefore need to be highly aware of their surroundings, but this is difficult because of the blind spots due to their helmet and small mirrors. To avoid incidents, an intuitive notification system that can specify direction and threat level is required. Therefore, we propose a system that uses haptic sensations to quickly notify motorcyclist of possible hazards or obstacles around the vehicle.

Our proposed hazard notification system uses vibro-tactile actuators installed in a motorcycle helmet. The system notifications flag the type of object, direction, and threat level surrounding the vehicle. We evaluate robustness against wind and motorcycle engine vibration. We also perform experiments to test the effectiveness of our proposed system. Section II presents related research. Section III presents system architecture considerations. Section IV presents the system architecture. Section V presents an examination of the vibration intensity to inform. Section VI presents the experiments under the influence of motorcycle engine vibration and the results of the experiments. Section VII presents the experiments under the influence of the driving wind and the results are presented.

II. PREVIOUS AND RELATED WORKS

For preventing accidents on motorcycles, there are two main approaches: motorcyclists are assisted in checking their surroundings or drivers around a motorcycle are assisted in recognizing motorcyclist locations. For the latter approach, a helmet with brake lights has been investigated for practical user [2]. However, we focus on the former approach in this study. Hazard notification systems have been proposed for four-wheeled vehicles [3] [4].

In addition, sensor systems, such as collision [5] or ground [6] detection methods, have been investigated for detection around a motorcycle. Many systems focused on the sensor, however, we would not sense issues, but also provide information to the motorcyclist because of lacking of the system. One study [7] proposed a smart helmet using a multimedia Internet of Things (IoT) sensor device and visual notifications. Many conventional notification methods for motorcycles rely on visual images in the motorcyclist's view [8] [9], such as front view, mirror, tachometer, speedometer, navigation system, and indicators. Therefore, there is the potential that excessive visual information may instead impact the motorcyclist's capacity to adhere to safe driving practices.

We focus on vibro-tactile notification as non-visual information. We could know the information by vibro-tactile because ancient motor cycles tells engine failure by irregular vibration to riders. Some systems vibrate a motorcycle's steering, but this approach is limited for notifications in front or behind the motorcycle [10]. We previously proposed a system for four-wheeled vehicles that uses haptic sensations to quickly notify drivers of possible hazards or obstacles surrounding the vehicle [11]. We examined the system's robustness against the different material types and layers used for the driving seat cushions of four-wheeled vehicles [12]. Seat on the motorcycle is vibrated by the engine, and it may be more difficult to notify by the vibration. In this study, we perform experiments under wind and engine vibration conditions to consider the viability of a highly intuitive notification system for motorcycles.

III. MOUNTING POSITIONS OF ACTUATORS FOR MOTORCYCLES

In this section, we represent the system architecture.

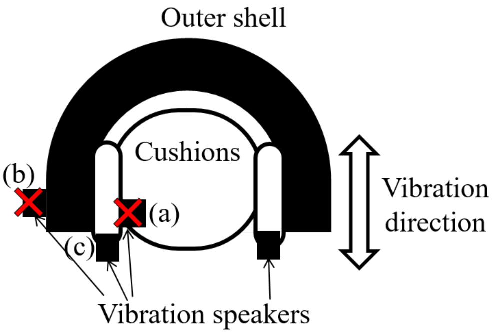


Figure 1: Proposed installation positions for actuators in a motorcycle helmet.

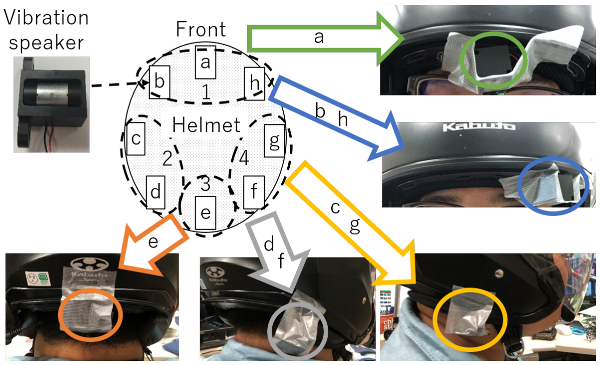


Figure 2: Experimental arrangement of mounted actuators.

A. *Notification Parts of a Body by Vibro-Tactile Actuators*

The proposed system aims to help motorcyclists correctly identify the directions of five vibrating motors, three intensity settings as the level of risk, and three obstacle types (i.e., pedestrians, vehicles, and motorcycles). The position of vibration is important for giving critical notifications. We can consider vibro-tactile actuators on the motorcyclist's arms, shoulders, or waist within a motorcyclist's suit or on the motorcyclist's head within a helmet. For locations on the body, the motorcyclist must use a wearable device, and there are different types of suit for different motorcycles types (e.g., Cruiser or Sport) because the riding posture is different. Drivers may also experience limited mobility in a suit, which would impact accurate notification.

By contrast, helmets are usually fitted to the motorcyclist's head, and vibration positions are not affected by varying postures, although they are limited to facing forward. Helmets are also required in many countries. Therefore, we choose helmets for our proposed system.

Figure 1 shows the possible installation positions within a motorcycle helmet. We cannot mount an actuator inside the helmet, as at (a), because the direct contact with the driver's head would be unsafe. We considered the helmet surface, as at (b), but our attempts showed that a very strong vibration would be needed. Therefore, we mount the actuators at the bottom of the cushion in the helmet, as at (c), so that the actuators vibrate vertically to each cushion.

We considered three types of vibration mechanisms: vibration motors, haptic reactors, and vibration speakers. Vibration motors can only produce sine waves and it is difficult to distinguish different categories, although they can achieve strong vibration. Although haptic reactors can realize a variety of vibrations, such as clicking, their vibration is too weak to produce notifications. We therefore propose a vibro-tactile notification system using a vibration speaker which can realize the vibration with strong and varied expression. For our proposed system, we utilized a vibrating speaker with an ACOUSTIC HAPTIC$^{\text{TM}}$actuator developed by Foster Electric Company Limited. The acoustic haptic actuator is a type of woofer that comes into direct contact with the driver's helmet.

B. *Mounting Positions of Actuators on a Helmet*

Motorcycle helmets have shields that can reduce visibility. They may also become foggy with weather and temperature, which further limits the motorcyclist's visibility. Backward of the motorcycles have more blind spot where such as motorcyclist cannot watch by the mirrors. Therefore, we consider the need for both backward and forward alerts.

Figure 2 shows the planned layout of actuators in the helmet. This helmet has four cushions (i.e., front, rear, right and left), as shown in sections (1) to (4) in Figure 2. To explore the vibro-tactile directional sense at the motorcyclist's head, we installed eight actuators as shown in Figures 2(a) to (h). Actuators (a), (b), and (h) were mounted on cushion (1), (c) and (d) were mounted on cushion (2), (e) was mounted on cushion (3), and (f) and (g) were mounted on cushion (4).

We conducted an experiment to evaluate the resolution of vibration on the human head. By determining the resolution of human-perceivable locations, we can determine which directions are identifiable. We performed the experiment with the engine in idle at $1500 \pm 300\text{rpm}$, which is frequently used as the typically speed range, on a Yamaha MT-01 motorcycle equipped with a V-twin cylinder 1670 cc engine. We conducted four trials with each participant. We apply five students between 19 and 22 years old as the participants. We randomly induced vibrations at each position with strengths ranging from -2dB to -12dB and participants estimated the position in the helmet.

Figure 3 shows the correct answer rates for the direction using all eight or only four actuators (one on each cushion: (a), (c), (e), and (g) in Figure 2). The vertical and horizontal axes denote correct answer rates and installation positions, respectively, and the green and orange bars respectively indicate results for all eight or only four actuators. The results demonstrate that there was confusion when multiple actuators were installed on a single cushion, leading to lower accuracy. By contrast, all participants had a 100% correct answer rate when four actuators were used. We therefore decided to utilize only one actuator per cushion.

IV. SYSTEM ARCHITECTURE FOR OUR PROPOSED SYSTEM

In line with the aforementioned experiment shown in Figures 2 and 3, we propose a vibro-tactile helmet as illustrated in Figure 4. Figure 4(A) shows the positions of the actuators (or vibration speakers) on the helmet. Figure 4(B) shows pictures of the different actuators in place; note that (b) and (d) are in the same position on the left and right sides of the helmet, so only one is shown.

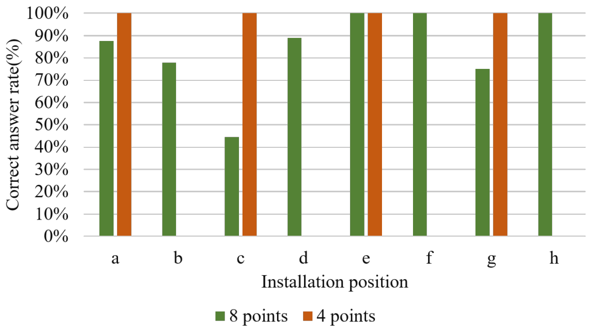


Figure 3: Correct answer rates according to the number and position of actuators.

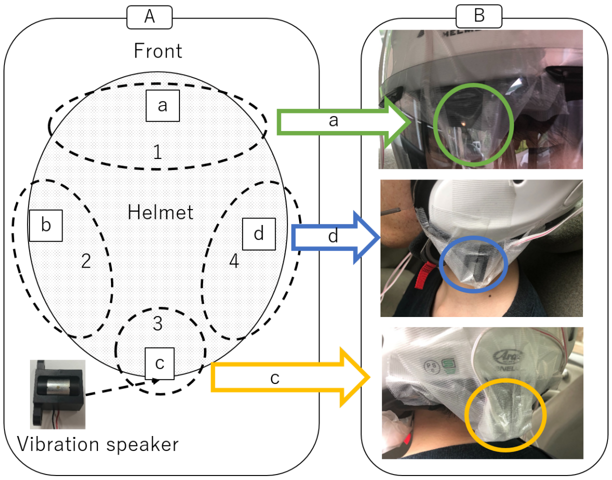


Figure 4: Overview of our proposed system.

The actuators shown in Figure 4 vibrate by transmitting sound data via the amplifiers. The sound data are deformed waves for three categories (i.e., pedestrian, four-wheeled vehicle, and motorcycle) the same as in our previous study for four-wheeled vehicles [12].

V. VIBRATION STRENGTH

In this section, we discuss the strength of the vibrations for our proposed system.

A. *Estimation of Strength Levels*

Our previous study in four-wheeled vehicles [11] had three vibration strength levels (i.e., large, medium, and small) as the level of risk. However, when riding a motorcycle, there is additional noise, such as from engine vibration or wind. Furthermore, we have not yet applied the vibration strength level concept to a helmet. Therefore, we consider the vibration strength of the three levels.

An experiment was conducted with five participants between 19 and 22 years old and the Yamaha MT-01 in idle. The strength pattern is defined by the difference in the sound pressure. We considered two strength patterns. Pattern A has a small difference between the three levels. We can utilize a fourth level if we can detect the differences in Pattern A. Pattern B has larger differences than Pattern A, with the larger vibration for four-wheeled vehicles adjusted so as not to prevent the motorcyclist from driving.

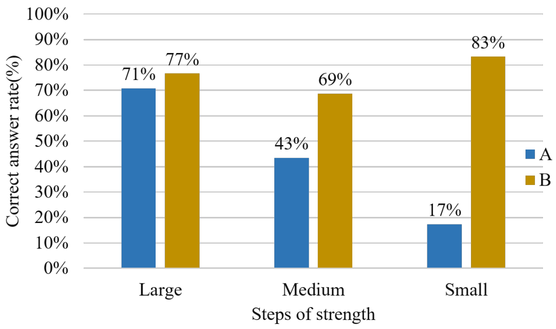


Figure 5: Correct answer rates for strength Patterns A and B.

The strength levels of Pattern A, ”large”, ”medium”, and ”small”, were respectively -6dB, -10dB, and -12dB from the original sound data which used by previous study [8], for all categories. The strength levels of Pattern B were different according to the category. In the cases of the pedestrian or motorcycle categories, ”large”, ”medium”, and ”small” were respectively -2dB, -8dB, and -12dB from the original sound data. In the case of four-wheeled vehicles, ”large”, ”medium”, and ”small” were respectively -3dB, -8dB, and -12dB from the original sound data.

This experiment was conducted using random directions, categories, and vibration strengths. Test participants answered ”large”, ”medium”, ”small”, or ”insensitive” as the levels of strength. Figure 5 shows the experimental results for both patterns. The vertical and horizontal axes denote correct answer rates and strength levels, respectively. The blue and brown bars respectively indicate Patterns A and B. Pattern A had low correct answer rates for ”medium” and ”small”, and as well as instances of ”insensitive” shown as 0 percent in Figure 5. Pattern B had correct answer rates of over 69% for each strength level. Thus, we adopt the notifying method by three strength levels with large interval such as Pattern B.

B. *Normalization by Head Sense*

In our previous study, we improved correct answer rates by using normalized and exaggerated waves for vibrations for the three categories (i.e., four-wheeled vehicles, motorcycles, and pedestrians) [12]. In this study, we similarly apply normalized and exaggerated waves to improve notification accuracy because many motorcyclists pointed out that vibration strength felt uneven depending on the installation position. Here, we normalize the vibration strength for the parts of the head an experiment on the motorcycle.

For normalization, we utilized three actuators, (a), (b), and (c), on the front, rear, and left cushions in Figure 4, respectively. Actuator (d) in Figure 4 is considered to have the same tendency as actuator (b). First, via a questionnaire, we determined the maximum and minimum strengths motorcyclists can detect with no stress. The results indicate that the difference between the maximum and minimum strengths for actuator (b) was smaller than that for the other positions. Thus, we used the maximum and minimum strengths, which participants feels as same as (b), for all the actuators. The maximum and minimum strengths were defined as ”large”

TABLE I: VIBRATION STRENGTH LEVELS AT EACH POSITION.

position	large	medium	small
a	$-6\mathrm{dB}$	$-10\mathrm{dB}$	$-14\mathrm{dB}$
b	$-8\mathrm{dB}$	$-12\mathrm{dB}$	$-19\mathrm{dB}$
c	$-6\mathrm{dB}$	$-10\mathrm{dB}$	$-13\mathrm{dB}$

and ”small”. The ”medium” strength level was not defined as the midpoint value (in decibels) between ”large” and ”small”, but defined as participants feel “medium” between ”large” and ”small” vibration. In this normalization, we utilized the vibration of the four-wheeled vehicle category [12]. Finally, we adjusted for the strength as shown in Table I, which presents the strength levels for each actuator position, noting that the side position is more sensitive than the front and back positions.

VI. EXPERIMENT

Finally, we conduct an experiment to verify the correct answer rates when using actuators mounted on a helmet when there are external factors, including wind and engine noise.

A. Experimental Trials by t-test

We decided to use t-tests to determine statistically significant results. We conducted an independent t-test for each strength level on actuators (a), (b), and (c) to compare the differences in correct answer rates under different wind and idling noises. We adopted a significance level of 5%, a moderate effect size of 0.5, and a detection rate of 80%. Possible answers were ”large”, ”medium”, ”small”, and ”insensitive”. Sample sizes for the answer of ”large” and the other strength levels were determined from one-sided and two-sided tests, respectively. From the t-test, sample sizes from which we could obtain a significant difference were 51, 64, and 64 samples for ”large”, ”medium”, and ”small” answers, respectively.

B. Correct Answer Rates during Idling

We conducted an experiment in the idling state to evaluate the robustness under engine vibration, as illustrated in Figure 6. Six test participants on the motorcycle answered when they felt a vibration. This experiment was conducted with the engine off as $0\mathrm{rpm}$, and rotating at $1000\mathrm{rpm}$, $1500\mathrm{rpm}$, and $2000\mathrm{rpm}$. In the case of $0\mathrm{rpm/h}$, the experiment was considered as a stable situation. For each engine speed include $0\mathrm{rpm/h}$, 51, 64, and 64 trials for ”large”, ”medium”, and ”small”, respectively, were performed at random. The vibration categories used were those applied to four-wheeled vehicles in our previous study [12].

Figure 7 shows the correct answer rates during idling rpm at $0\mathrm{rpm}$, $1000\mathrm{rpm}$, $1500\mathrm{rpm}$, and $2000\mathrm{rpm}$, respectively. The blue, red, and yellow bars respectively indicate ”large”, ”medium”, and ”small” as answered by the participants. The vertical and horizontal axes of each figure denote the correct answer rate and the three levels of signal strength, respectively. For example, 10% of participants answered ”medium” for the ”large” strength level given by an actuator at $1000\mathrm{rpm}$, as shown in Figure 7(b).

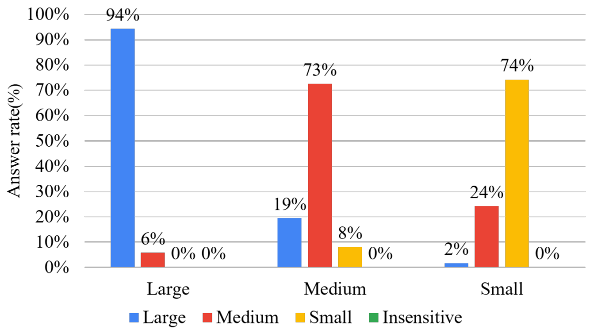
Figure 6: Overview of the experiment for the stable situation.

We defined the correct answer rate as the percentage of matches between the answers of participants and the actual level of vibration strength. For example, in the case of Figure 7(b), the correct answer rates for ”large”, ”medium”, and ”small” were 90%, 72%, and 83%, respectively. Let us focus on the ”medium” strength level in Figure 7. We can confirm that participants felt as more strong vibration identifying the ”medium” strength level because participants answered ”large” more often than they did ”small”. The correct answer rates were lowest in the case of Figure 7(d). This may be due to the high engine rotation causing stronger vibration and noise from the motorcycle, obscuring the vibration from the actuators.

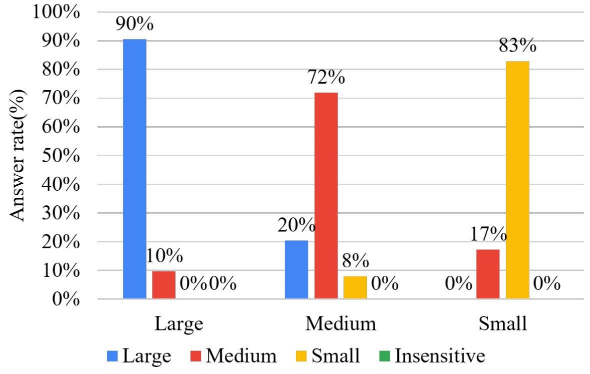
VII. EVALUATION OF DRIVING SCENARIO

We conducted an experiment with six participants using a car to evaluate degradation in accuracy due to wind. We used the car because of safety and difficulty to collect correctly answers of notification. Although the strength of the traveling wind is little different between cars and motorcycles, the effect of the wind can be measured. We compared the wind noise between the car and the motorcycle, and found that the wind noise on the motorcycle was almost same as on the car with all windows open. Each participant evaluated the four speeds of $0\mathrm{km/h}$, $60\mathrm{km/h}$, $80\mathrm{km/h}$, and $100\mathrm{km/h}$. At each speed, we performed 51, 64, and 64 trials with ”large”, ”medium”, and ”small” strength levels, respectively, at random. The actuator vibrated for 5–10 s at random for each trial. In the case of $0\mathrm{km/h}$, we conducted the experiment as a stable situation, as same as section 6.2. In the other cases, we used a highway. Figure 8 shows the experimental highway route. This route has two lanes in each direction limited to $100\mathrm{km/h}$, and three entrances and exits shown as (1), (2), and (3). We set up sections of $11.1\mathrm{km}$ between (1) and (2), $20.3\mathrm{km}$ between (2) and (3), and $9.2\mathrm{km}$ between (3) and (1).

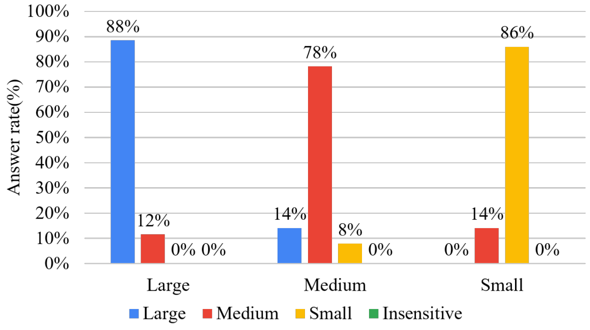
The experiment was conducted at speeds of $80\mathrm{km/h}$, $100\mathrm{km/h}$, and $60\mathrm{km/h}$ between (1) and (2), (2) and (3), and (3) and (1), respectively. Figure 9 shows the seating positions of the participant in this experiment. All windows of the car were open and the helmet shields were closed. Before the experiment, participants were provided with examples of the three strength levels (i.e., ”large”, ”medium”, and ”small”) at position (b) of 4. We limited the experiment to the four-wheeled vehicle category. The experimental results were saved as movie files and evaluated via post-processing.



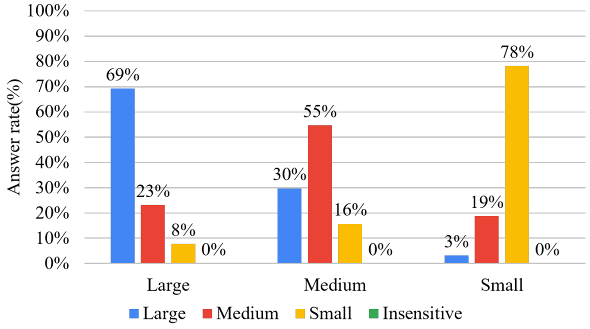
(a) 0rpm



(b) 1000rpm



(c) 1500rpm



(d) 2000rpm

Figure 7: Answer rates for different strength levels at (a) 0 rpm, (b) 1000 rpm, (c) 1500 rpm, and (d) 2000 rpm.

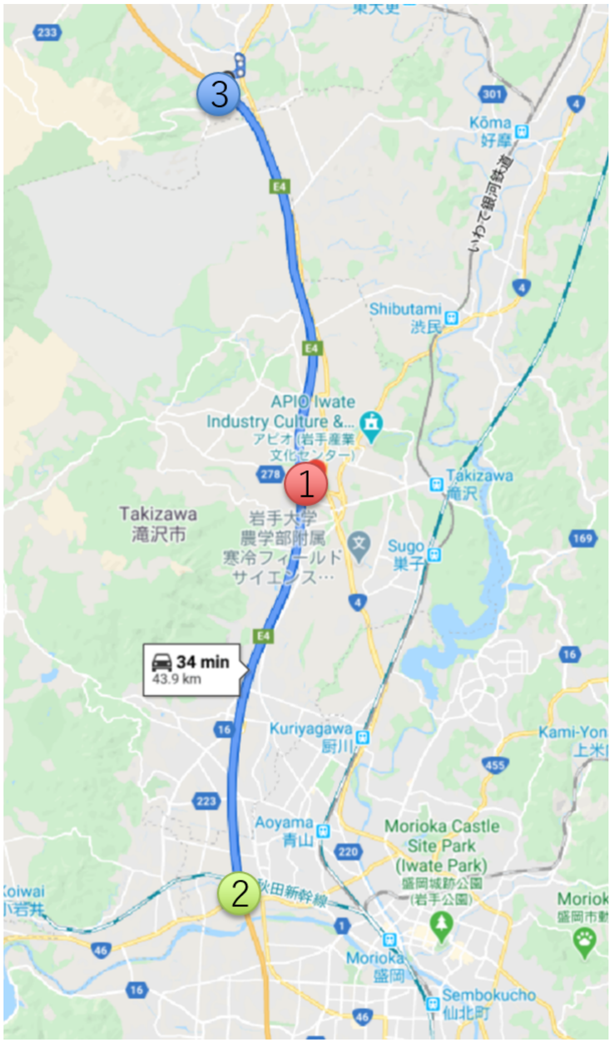


Figure 8: The course of the experiment on a highway.

Figure 9: The seating position of participants in the vehicle.

Figure 10 shows the correct answer rates at driving speeds of $60\mathrm{km/h}$, $80\mathrm{km/h}$, and $100\mathrm{km/h}$. The vertical and horizontal axes of each figure denote the correct answer rate and the three levels of signal strength, respectively. In the case of Figure 10(a), in 94%, 73%, and 74% of all trials, the test participant answered ”large”, ”medium”, and ”small” for large, medium, and small vibration strengths, respectively, so these are the correct answer rates. Figure 10(b) indicates a high correct answer rate for large vibration. Test participants tended to be more likely to select strong vibrations. In the case of Figure 10(c), the correct answer rates were increased and decreased, respectively, for medium and large vibrations as compared to Figure 10(b). In Figure 10(d), a high correct answer rate was obtained even for small vibration. From Figures 10(c) and 10(d), the ”medium” strength level showed only small differences in the incorrect answer rate as compared to ”large” and ”small”. Therefore, ”medium” is considered to be appropriate in the high-speed case. We expect a higher notification accuracy can be achieved by adjusting the strength automatically depending on outside noise. We also found that notification accuracy was more degraded by engine rotation than by wind noise, which should be a consideration for practical implementation.

VIII. CONCLUSIONS

It is difficult for motorcyclists to recognize objects in their surroundings because of the many blind spots from their helmets and small mirrors. Furthermore, accidents are more serious for motorcycles than for four-wheeled vehicles because of the mortality. We therefore proposed a notification system for motorcycles based on previous works for four-wheeled vehicles. In our system, parts of the helmet vibrate corresponding to direction of a hazard, the category of an object, and the level of risk. We considered the strength of vibration to determine three strength levels. We evaluated the accuracy of our proposed notification method for motorcycles using haptic actuators in windy and idling situations. We demonstrated the effectiveness of our notification method even for winds of $100\mathrm{km/h}$. We expect improved notification accuracy can be achieved by adjusting vibration strength according to the motorcycle’s speed. Various types of helmets will be studied in the future.

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REFERENCES

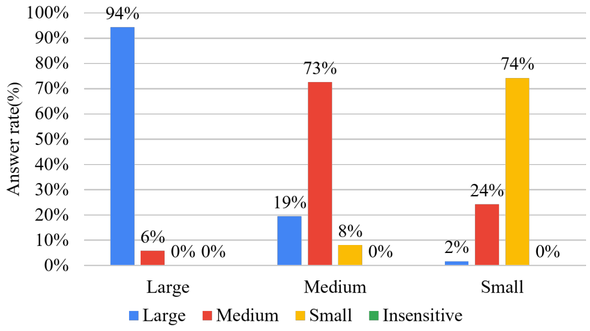
[1] “Statistics about road traffic annual report, national public safety commision and national police agency,” 2018. [Online]. Available: https://www.e-stat.go.jp/en/stat-search/files?page=1&layout=datalist&toukei=00130002&tstat=000001027457&cycle=7&year=20180&month=0&stat_infid=000031800894

[2] “Brake free helmet light. digital image. indiegogo,” 2020. [Online]. Available: https://www.indiegogo.com/projects/brakefree-the-smart-brake-light-for-motorcyclists#/

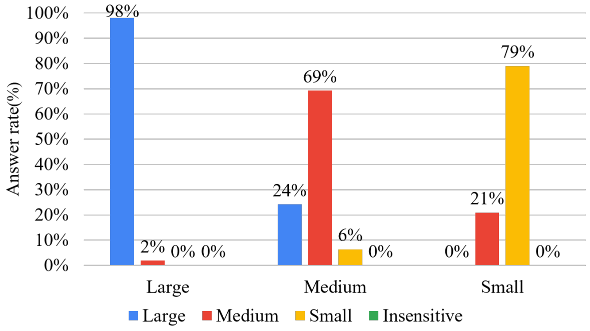
[3] W. Chang, W. Hwang, and Y. G. Ji, “Haptic seat interfaces for driver information and warning systems,” International Journal of Human-Computer Interaction, vol. 27, no. 12, Dec. 2011, pp. 1119–1132. [Online]. Available: https://doi.org/10.1080/10447318.2011.555321

[4] Y. Gaffary and A. Lécuyer, “The use of haptic and tactile information in the car to improve driving safety: A review of current technologies,” Frontiers in ICT, vol. 5, Mar. 2018, p. 5. [Online]. Available: https://doi.org/10.3389/fict.2018.00005

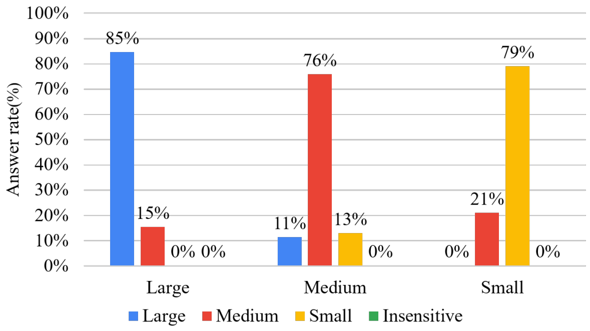
[5] M. Muzammel, M. Z. Yusoff, and F. Meriaudeau, “Rear-end vision-based collision detection system for motorcyclists,” Journal of Electronic Imaging, vol. 26, no. 3, May 2017, p. 033002. [Online]. Available: https://doi.org/10.1117/1.jei.26.3.033002



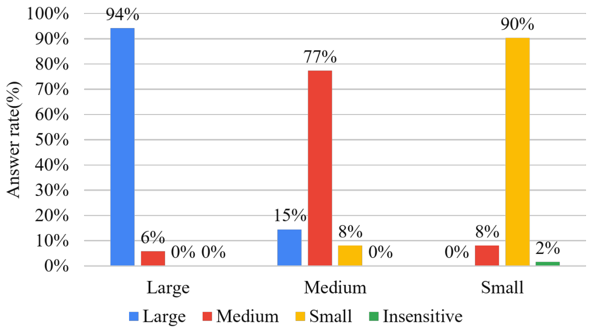
(a) 0km/h



(b) 60km/h



(c) 80km/h



(d) 100km/h

Figure 10: Answer rates for strength levels at each speed.

[6] G. Gil, G. Savino, S. Piantini, and M. Pierini, “Motorcycles that see: Multifocal stereo vision sensor for advanced safety systems in tilting vehicles,” Sensors, vol. 18, no. 2, Jan. 2018, p. 295. [Online]. Available: https://doi.org/10.3390/s18010295

[7] M. I. Tayag and M. E. A. D. V. Capuno, “Smart motorcycle helmet: Real-time crash detection with emergency notification, tracker and anti-theft system using internet-of-things cloud based technology,” International Journal of Computer Science and Information Technology, vol. 11, no. 03, Jun. 2019, pp. 81–94. [Online]. Available: https://doi.org/10.5121/ijcsit.2019.11307

[8] V. H. Tran, D. Muscat, J. R. Cruz, A. M. Carrillo, D. A. A. Alonso, and E. Chavez, “Motorcycle and helmet providing advance driver assistance,” U.S. Patent Application No. 13/897,570, 2013.

[9] Crosshelmet, “Cross helmet x1 - transform your riding experience,” 2020. [Online]. Available: https://crosshelmet.com/

[10] C. Inc., “Blind spot detection & lane change assist,” 2020. [Online]. Available: https://www.continental-automotive.com/en-gl/2-Wheeler/Safe-Mobility/ARAS/Blind-Spot-Detection

[11] A. Suzuki, Y. Murata, and M. Hayashi, “Notification of hazards around a vehicle using seat actuators,” in 25th ITS World Congress. Copenhagen, Denmark: ERTICO, September 2018, pp. AP–TP1335.

[12] A. Suzuki, K. Horie, S. Otobe, Y. Murata, and S. Fujimura, “Hazard notifications around a vehicle using seat actuators,” The International Journal on Advances in Intelligent Systems, vol. 13, no. 1 and 2, 2020, pp. 59–68, iSBN:978-1-61208-720-7,ISSN:1942-2679.