2022 International Workshop on Smart Info-Media Systems in Asia (SISA 2022), Sep. 15–16, 2022

Development of In-Vehicle Auditory Signal Evaluation Platform in A Driving Simulator

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***Abstract*—Advanced driver-assistance systems (ADAS) are generally used to support a safe drive by detecting potential risk factors beforehand and informing the driver of them. However, if all the services in ADAS rely on visual-based technologies, the driver becomes increasingly burdened and exhausted. The driver should be back out of monitoring tasks other than significantly important ones from the perspective of alleviating the burden of the driver as long as possible. As a solution to this problem, in-vehicle auditory signals to inform the driver of inattention have been appealing as another approach to altering visual suggestions in recent years. In this paper, we developed an in-vehicle auditory signals evaluation platform in an existing driving simulator. In addition, using an in-vehicle auditory signal, we evaluate the effectiveness of this evaluation platform.**

I. Introduction

Autonomous vehicles have been attractive as a representative infrastructure in the next generation. Many automotive, electronics, and IT service companies have been dedicated to developing such vehicles. Regardless of this trend, there remains a challenging issue that replacing all existing vehicles with fully automated vehicles is infeasible, resulting in a situation that mingles a variety of vehicles in the future [1].

Advanced driver-assistance systems (ADAS) are a prevailed system that supports a safe drive by detecting potential risk factors beforehand and informing the driver of them. Such systems can take over many tasks such as longitudinal and/or lateral guidance of a vehicle, with the goal of alleviating the burden of the driver. Since most accidents are caused by the inattention of a driver, general ADAS provides a service that detects the inattention and ineffective visual search pattern and visual suggestions such as more suitable eye fixation locations [2]. However, if all the services in ADAS rely on visual-based technologies, the driver becomes increasingly burdened and exhausted. The driver should be back out of monitoring tasks other than significantly important ones from the perspective of alleviating the burden of the driver as long as possible. In addition, visual-based supports for drivers, especially beginners, are less suitable for driving situations than for experienced drivers since it has the possibility that inducing inattentive driving by visual guidance.

In-vehicle auditory signals to inform the driver of inattention have been appealing as another approach to altering visual suggestions in recent years. In a classical manner, the auditory warning has been utilized [3]. The auditory signals, however, have the potential that intuitively inflames a variety of sentiments by taking advantage of auditory effects derived from different timing, tones, and volumes, thus it can exploit the potential of encouraging the driver to pay attention and conjecture the risk of accidents. Despite that, the impression of the same auditory signal strongly depends on people since they have their own feeling emotions. Therefore, there is a demand for a simulation platform to evaluate the effectiveness of a variety of auditory signals.

In this paper, we develop an in-vehicle auditory signals evaluation platform in an existing driving simulator. In addition, using an in-vehicle auditory signal, we evaluate the effectiveness of this evaluation platform. The remainder of this paper is organized as follows: Section II addresses related work. Section III addresses the in-vehicle auditory signals evaluation platform. We describe the structure of a driving simulator, where we implement our developed function and present the auditory signal function based on the beat in detail. In Section IV, we conduct experimental scenarios to evaluate the effects of auditory factors on driving behavior and discuss the results. Through the experiment, we confirm the effectiveness of this evaluation platform. Finally, Section V concludes the remarks and addresses the future task.

II. Related Work

A. Features of each information presentation method

When it comes to driving a vehicle, the driver needs to pay close attention to the surrounding and process much information from eyes and ears. Unfortunately, however, the driver is too burdened to notice and deal with all the things that happens around the driver, resulting in accidents in the case. Due to the reason, there has appeared much work that supports the driver in the visual and auditory manners. The authors in [4] developed the vehicular display to visually support the driver in order to realize legibility and operability without sacrificing the safety and comfort during driving. For several years, the technology called HUD (Head-Up Display) for automobiles has been emerged, where an image to guide the driver is projected on the windshield. In 2017, the world's first in-vehicle 3D augmented reality head-up display (3D-ARHUD) was developed [5]. However, it has been pointed out that visual warnings may go unnoticed by the driver and may distract the driver and increase the risk of accidents [6]. Thus, the driver support technologies by the visual manner are not very suitable for notification, especially in dangerous situations where the immediate response is required. In the work in [7], the authors stated that in-vehicle auditory signals can be

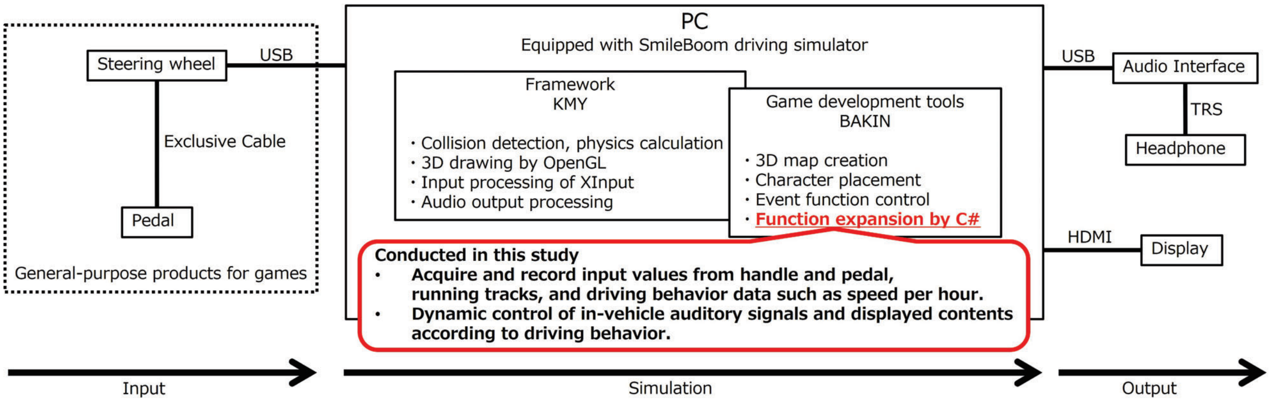

Fig. 1. An overview of the driving simulator.

more important than visual guidance to guarantee the safety of drivers and vehicles. Furthermore, the work [8] addressed that the human auditory system does not interfere, unlike the visual manners.

As mentioned above, in-vehicle auditory signals are expected to play a major role as a guidance technology for drivers, but there are still many problems. Conventional in-vehicle auditory signals are uniform, making it difficult for drivers who hear the signals to understand what the signals mean. Furthermore, even the same auditory signal will give different impressions to drivers in different driving contexts in which they hear it. In this context, there is the work that attempted to find appropriate acoustic characteristics of in-vehicle auditory signals in order to benefit the effectiveness of auditory signals [9]. In addition, epoch-making warning sounds that did not exist before have been developed, such as the bicycle-based warning sound system featured in [10].

There are becoming more and more chances to utilize in-vehicle auditory signals in the field of the driver-assistance systems, and there have appeared a demand for a platform to evaluate the effect of auditory signals.

B. Value and use of driving simulator

Driving simulators are tools for simulating the operation and behavior of automobiles and are useful both in academia for research purposes and in industry for design purposes. The reason for this is that virtual simulation allows the systems to be developed and evaluated safely in a shorter period of time and with less investment. In the work [11], Bruck et al. investigated and summarized the value, mechanism, and features of state-of-the-art driving simulators. Most of existing drive simulators are strongly aware of vision, and 3D projector is employed to reproduce the visual guidance for pursuing the reality of automobiles [12]. In addition, high-performance and large-scale driving simulators for visual guidance have been introduced in order to enhance immersive feelings with vibration and tilt of the driver's cab [13]. On the other hand, auditory signals are another manner to enhance immersive feelings, but inferior to the visual one. The work in [14] proposed a 3D sound image localization as a highly effective driving assistance, expanding the possibilities of driving assistance using in-vehicle auditory signals. Unfortunately, to the best of our knowledge, no platform that aims to flexibly evaluate the user interface and user experience of various in-vehicle auditory signals is proposed. Therefore, in this paper, we propose a simple evaluation platform for any in-vehicle auditory signals using a driving simulator.

III. In-Vehicle Auditory Signals Evaluation Platform

A. Target Driving Simulator

We show the system overview of the driving simulator used in this study in Fig. 1. Fig. 1 shows a flow from inputting driving behavior to a PC to presenting dynamically simulated results based on the inputs to the driver. The driving simulator installed in the PC is developed and provided by SmileBoom[1]. The system of the driving simulator is based on SmileBoom's KMY game development framework that integrates physical calculations, 3D drawing by OpenGL, inputs processing, and audio output processing as an interface. The game development tools called BAKIN can run on the KMY. This tool supports 3D map creation, place objects such as people, vehicles, and event functional control. In addition, here we have added a function that dynamically sounds in-vehicle auditory signals according to the driving situation and records driving behavior such as steering wheel and pedals operation and speed. We show the driving simulator's appearance in Fig. 2. As seen in Fig. 2, the steering wheel and pedals for driving are equipped on the desk. In addition, the headphone and display are connected to the computer, and our developed auditory signals output throughout its headphone. The output from the headphone is stereo. One display is used, and its size is 28 inches.

We have generated several maps in advance. As shown in Fig. 3, we can start on the map with an automatic transmission vehicle driven by the steering wheel, accelerator, and brake. The maximum speed is about 100 km/h. On this driving

[1]SmileBoom Co., Ltd.; A game development company headquartered in Sapporo, Hokkaido, Japan.

Fig. 2. Appearance of the driving simulator.

Fig. 3. Driver perspective screen.

simulator, the vehicle is supposed to have a right-hand drive and the roads are supposed to drive on the left side, simulating the traffic situation in Japan.

B. Beat-based Auditory Signals towards Vehicle Speeds

We describe an in-vehicle auditory signal implemented as a sample to evaluate the effectiveness of the proposed evaluation platform. The in-vehicle auditory signal informs the driver of the speed of a vehicle, aiming at the speed reaching a target one such as a legal speed limit.

In this work, we employ the beats that are produced by the superposition of two sine waves of slightly different frequencies but identical amplitudes. Assuming that the frequencies of the two superposed sound sources are respectively f_1 and f_2 [Hz], the beat frequency f [Hz] is expressed by the following equation.

$$f = |f_1 - f_2| \tag{1}$$

Such acoustic effect enables the driver to intuitively feel the difference between the current and target speed and encourages the driver to adjust the speed for the target speed.

We have configured the auditory signal based on beats as shown in Fig. 4. This figure shows an example of the simple schematic diagram of the characteristics of the beat (frequency/pitch change) when the target speed is 30 km/h. As shown in the figure, the frequency and pitch of the beats

Speed per hour	0	10	20	30	40	50	[km/h]
Beat's							
・Frequency	High ←----------→ Low			None	Low ←----------→ High		
・Pitch	Low ←--------------→			Medium	←---------------→ High		

Fig. 4. An example of the simple schematic diagram of the characteristics of the beat (frequency/pitch change) when the target speed is 30 km/h.

depend on the vehicle speed. If the vehicle runs significantly faster than a target speed, the frequency and pitch of the beats become higher. The detail of the frequency and pitch for the beats is described as follows:

- The larger the absolute value of the difference from a target speed, the higher the beat frequency.
- The smaller the absolute value of the difference from a target speed, the lower the beat frequency.
- At around a target speed, the beat disappears and the sound with a certain height (assumed to be F Hz) sounds.
- The slower the speed than a target speed, the lower the pitch of the beat becomes lower than F Hz.
- The faster the speed than a target speed, the higher the pitch of the beat becomes higher than F Hz.

The driver is encouraged to aim at a beat-free state by the beats. By using the above in-vehicle auditory signal, it is considered possible to adjust the speed without relying on the speed meter.

IV. Experiments

A. Experimental Scenario

In order to evaluate the effectiveness of our developed in-vehicle auditory signals evaluation platform, we have conducted experimental evaluations with the beat-based auditory signal. Since this work aims to alleviate the burden of the driver, we have conducted the following experimental scenario: The participants drive the vehicle to go straight on the left lane in the condition that they accelerate up to 30 km/h as the target speed and maintain its speed as long as possible. We have evaluated the accuracy that the duration of driving within 25-35 km/h out of the total driving time. In addition, after driving, we evaluated the burden on a scale of one to seven through personal questionnaires about how the participants felt burdened by the driving scenario. Our experiments have been conducted on 14 people with good hearing and visual acuity.

In the experiments, we have compared the following two methods to adjust the speed.

1) **Speed meter (integer):**
   A speed meter that displays the current speed as an integer at the bottom of the display.
2) **Beat (frequency/pitch change):**
   An in-vehicle auditory signal in which the beat frequency and pitch change according to the running speed.

We assume the traditional method for comparison that the drivers adjust the speed by checking the speed meter. In addition, we employ the other method to adjust the speed using the developed in-vehicle auditory signal based on the beat, which has been described in Section III-B. Table I shows

TABLE I
VEHICLE SPEEDS AND FREQUENCIES OF TWO WAVES AND BEATS.

Speed [km/h]	Freq. of two sine waves [Hz]	Freq. of beat [Hz]
0-7	170 & 160	10
7-11	175 & 166	9
11-13	180 & 172	8
⋮	⋮	⋮
25-27	215 & 214	1
27-33	220 & 220	0 (Beat-free)
33-35	225 & 226	1
⋮	⋮	⋮
47-49	260 & 268	8
49-53	265 & 274	9
53-	270 & 280	10

TABLE II
SPEED ADJUSTMENT ACCURACY AND DRIVER BURDEN.

Speed presentation methods	Accuracy	Burden (1 to 7)
Speed meter (integer)	78 %	4.71
Beat (frequency/pitch change)	70 %	2.93

the frequency of the beat at each speed and the frequency of the two sine waves that make up the beat. If the developed auditory signal method is employed, the driver cannot see the speed meter. In contrast, the beat is not produced while the speed meter method is taken.

B. Results

Table II shows the experimental results. Accuracy represents the duration of driving within 25-35 km/h out of the total driving time. Burden represents the burden on the driver based on the questionnaire on a scale of one to seven. As the results, we demonstrated that the speed meter method was superior in terms of accuracy, but the beat was not significantly inferior since it can maintain the speed by 70 % during driving. In addition, when an average t-test using a pair of samples was performed on the driver's burden, it was found that the beat (frequency/pitch change) had a significantly smaller burden than the speed meter ($t(13) = 3.79,\ p < 0.01$). Considering multitasking during a real driving environment, speed adjustment using appropriate in-vehicle auditory signals can alleviate the burden on the driver compared to speed adjustment using a speed meter. From these results, the usefulness of in-vehicle auditory signals and the effectiveness of this in-vehicle auditory signals evaluation platform were shown.

V. CONCLUSIONS

In this paper, we developed an in-vehicle auditory signals evaluation platform in an existing driving simulator. In addition, in order to evaluate the effectiveness of our developed evaluation platform, we have conducted experimental evaluations with the beat-based auditory signal. The experimental results show that the burden on the driver can be alleviated by appropriate in-vehicle auditory signals. Similarly, from the results, the combination of visual and auditory suggestions implies to yield the further effectiveness for driving. Through the experiments, we showed that the proposed platform is effective in evaluating in-vehicle auditory signals.

In the future, we will improve the stereophonic engine in this driving simulator to correspond to the acoustic characteristics peculiar to the vehicle interior. Through the improvement, we want to realize a platform that can carefully evaluate in-vehicle auditory signals that have undergone 3D sound localization processing. Furthermore, we plan to study a method for easily reproducing traffic conditions that match the experimental scenarios by utilizing NPC (Non-Player Character) technology.

ACKNOWLEDGMENT

We would like to express our deep gratitude to SmileBoom Co., Ltd. for developing the system that forms the basis of the driving simulator used in this research.

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