Periodic Tactile Feedback for Accelerator Pedal Control

Yosuke Kurihara [1] Taku Hachisu [1,2] Michi Sato [1,2] Shogo Fukushima [1,2] Hiroyuki Kajimoto [1,3]

[1] The University of Electro-Communications, [2] JSPS Research Fellow, [3] Japan Science and Technology Agency

ABSTRACT

Sensing the position and movement of the accelerator pedal in a vehicle is important for acceleration control and safety while driving. The accelerator pedal is controlled by the foot, but precise adjustment requires much training because the driver must rely on somatosensory cues, which provide limited feedback. In this study, we propose periodic tactile feedback for the accelerator pedal to provide an additional tactile cue. We conducted an experiment using a driving simulator to compare the lap time, the rate of off-track incidents and the subjective evaluation of controllability recorded in questionnaires. The experiment confirmed that the feedback makes the control of acceleration easier and facilitates safer driving.

Keywords: Accelerator pedal, safe driving, user interface, vibrotactile feedback.

Index Terms: H.5.2 [Information Interfaces and Presentation]: User Interfaces — Haptic I/O.

1 INTRODUCTION

The control of vehicle acceleration is important for safety. Cues with which to grasp the position of the accelerator pedal include the tachometer, speedometer, engine sound and proprioception of the foot. However, drivers cannot view the tachometer or listen to the engine sound continuously while driving since they need to pay attention to other visual and auditory cues while driving (e.g., they must look out for pedestrians and listen for the approach of other cars). Therefore, the proprioceptive cues of the foot are considered to be especially important for the control of the accelerator pedal by the foot. Compared with the case for general body movement, which is grasped by integrating multisensory cues such as visual, acoustic and haptic cues (especially visual cues in the case of for fine motion [1]), the lack of visual and auditory cues makes pedal control difficult. Drivers must acquire the skill of pedal control to some level at driving school, but good control takes a long time to learn.

In our previous study, we proposed the augmentation of human proprioception by adding periodic tactile feedback as a new tactile cue that is synchronized with body movement. A kinesthetic sense at the elbow joint, for instance, can be emphasized by a simple mechanical device that mimics a rotary switch presenting a “tick-tack feeling” [2]. Periodic feedback is often used for a dial on the dashboard of an automobile, which allows the driver to adjust the dial without looking [3]. Although the system is quite simple, we can regard it as a type of haptic augmented reality system.

In this paper, we propose a periodic tactile feedback for a vehicle accelerator pedal that is synchronized with the position of the pedal. We expect that the feedback will emphasize the sense of position and movement of the pedal so that the driver can accurately adjust the pedal position to the appropriate acceleration.

{kurihara, hachisu, michi, shogo, kajimoto}@kaji-lab.jp

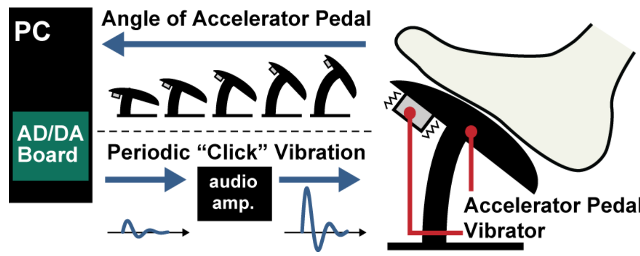

Figure 1: Periodic vibrotactile feedback for accelerator pedal.

2 RELATED WORKS

A number of prior works have proposed driving support systems. Intelligent speed adaption is a general term for systems that support a driver’s speed control [4]. The systems warn the driver through an alerting display and sound when the vehicle speed exceeds the speed limit. If the driver does not reduce speed, the system automatically reduces the speed by manipulating the engine ignition and braking systems and increasing the counterforce of the accelerator pedal. Adaptive cruise control [5] is a vehicle following support system that automatically adjusts the vehicle speed to maintain a safe following distance and avoid rear-end collision [6]. Particularly, haptic feedback for driving interfaces has been widely proposed to reinforce collision warning [7][8] and navigation [9][10]. Similar types of systems have already been installed in commercially available vehicles [11][12].

The technologies proposed in these prior works are fundamentally “automated” driving support systems. However, in terms of the human interface, these systems present the status of the vehicle by a haptic cue. In other words, the system “teaches” the correct speed or distance and the drivers are required to obey the instruction, similar to the case for existing human interfaces for body movement instruction[13].

In contrast, our hypothesis is that “enhancing” the sensation is more effective for driving support than “teaching” the answer. Unlike the automated system, our system does not correct errors, but the additional tactile cue makes it easier for the driver to grasp the angle of the accelerator pedal, simplifying the control task, and allowing the driver to adjust the acceleration more accurately. While there has been research on the augmentation of the driver’s sense such as ground condition sensing [14] and invisible obstacle awareness [15], we focused on enhancing the sense of position and movement of the accelerator pedal. Additionally, this system would be effective for learning accelerator control, because drivers do not lose proactiveness [16] when controlling the pedal. Note that our system would be combined with an automated system

3 IMPLEMENTATION

Figure 1 shows the structure of the periodic tactile feedback system. The system consists of an accelerator/brake pedal controller for

PlayStation 3 (Logicool, Driving Force GT), an AD/DA board (Interface Corp., PCI-3523A), a personal computer (PC), an audio amplifier (Rasteme Systems Co., Ltd., RSDA202) and a vibrator (Alps Electric Co., Ltd., Force Reactor). The PC receives the position of the accelerator pedal via the AD/DA board by reading the output from the potentiometer attached to the pedal. When the pedal angle reaches borders that equally divide the range of movement into six segments, the PC outputs an instantaneous sinusoidal signal to actuate the vibrator. Owing to the equal spacing and instantaneous stimulation, the user perceives a periodic clicking feeling on the plantar fascia through a sock. In a preliminary experiment, we tested other vibrotactile actuators, but we adopted the Force Reactor for two reasons. First, it has the ability to output a 240-Hz vibrotactile stimulus, which presents a tactile sensation most vividly for the human. Second, it has a fast response characteristic, which is important for real-time tactile feedback.

For vibrotactile stimuli, we employed a model of a decaying sinusoidal waveform [17]:

$$Q(t) = A(v)e^{-Bt}\sin(2\pi f t), \tag{1}$$

where Q is the amplitude of vibration, t is the time elapsed since impact, v is the impact velocity (set to be constant in this implementation), A is the initial amplitude, which is a function of v, B is the decay rate, and f is the vibration frequency. The model represents vibration related to collision, and can express many types of materials with the varying A, B, and f. In this experiment, we assigned $A = 66\ \mathrm{m/s^{-2}}$, $B = 150\ \mathrm{s^{-1}}$, and $f = 240$ Hz so that the amplitude decayed to nearly zero after one or two waves, and the signal was perceived as a short click. The stimulus duration was between 4.2 and 8.4 ms. The stimulation frequency of 240 Hz is known to be the vibration frequency that the Pacinian corpuscle is most sensitive to. As our purpose is to present a signal to a wide area such as the whole surface of the planter fascia, stimulation of the Pacinian corpuscle is considered appropriate. Note that this click feeling does not generate a physical force on the accelerator pedal since it is a mere vibration of the pedal.

4 EXPERIMENT 1: ENHANCEMENT OF PEDAL CONTROL

The purpose of the experiment with a driving simulator was to verify our hypothesis that feedback in the form of a periodic clicking feeling synchronized with the angle of the accelerator pedal enhances the control of the pedal. We compared lap times, rates of off-track incidents (i.e., incidents in which the vehicle completely leaves the road) and subjective controllability as determined from questionnaires.

Figure 2: Overview of the experiment.

4.1 Experimental conditions

Figure 2 is an overview of the experimental environment. We prepared a special driving seat, a 65-inch three-dimensional television and the PlayStation 3 video game GRAN TURISMO 5 [18] as a driving simulator. We conducted the experiment with the participants wearing socks to avoid the effect of the thickness of the sole of a shoe. Because of the amplitude of the vibration can easily be set higher, the system can be applied to a practical scene.

The experimental task was to drive on the training course for throttle control (B License, No.07) with pedals that incorporated our clicking feedback system. This training course was considered more suitable than ordinary racing courses for our purpose, since participants tend to rely on rough control (full throttle and hard braking) when driving the ordinary racing course, whereas the training course has many curves and encourages participants to adjust their speed through fine accelerator pedal control.

We recruited 31 male and 11 female participants, aged between 18 and 30 years. The participants were divided into two groups: group A and B, based on the order of the feedback condition. The participants in group A repeated one lap of driving for 30 times (main trials) under the with-feedback condition. Afterward, three trials (additional trials) were conducted under the without-feedback condition. Group B was tested under the opposite order of the feedback conditions.

4.2 Experimental procedures

The participants were asked to rank their confidence in terms of their driving skill in real life at one of four levels: 1) confident, 2) not that confident, 3) the confidence of a Sunday driver (i.e., someone who drives infrequently), 4) having no driver's license. The experimenter decided the feedback condition (with or without feedback) for each participant, to balance the numbers of participants having a certain level of driving skill in the two groups. The participants were instructed to drive the course 30 times as quickly as possible in their training of acceleration control. Before the first, sixth, eleventh, and twenty-first trials, they saw a replay of a video of ideal driving. In this training, if all four tires left the road, the trial was interrupted immediately and an "off-track incident" was recorded. The off-track trial was also counted as one of 30 times of trials

The participants driving under the feedback condition were told that there were five clicks for the accelerator pedal. They were asked to control the car with three actions: rotation of the steering wheel, application of their right foot to the accelerator pedal, and application of their right foot to the brake pedal. Finally, they wore three-dimensional glasses and headphones, and the trial began. The experimenter recorded the lap time for each trial. The trial was counted even if the participant left the track.

After the 30 main trials, three additional trials were conducted under the other condition (without or with clicking feedback) to subjectively compare the effect of the clicking feedback for the same participants.

At the end of the experiment, the participants were asked questions about whether the clicking feedback made the accelerator easier to control, and to freely comment on their impression of the clicking feedback.

5 EXPERIMENT 1: RESULTS AND DISCUSSIONS

The following participants were omitted from the analysis.

(1) Participants who play racing games habitually; experienced participants were not considered as naïve. There were three such participants in the with-feedback group, and one in the without-feedback group.

(2) Participants who left the track in more than 15 trials; the driving technique of these participants was too poor to be

analyzed. There was one participant in with-feedback group and three in the without-feedback group.

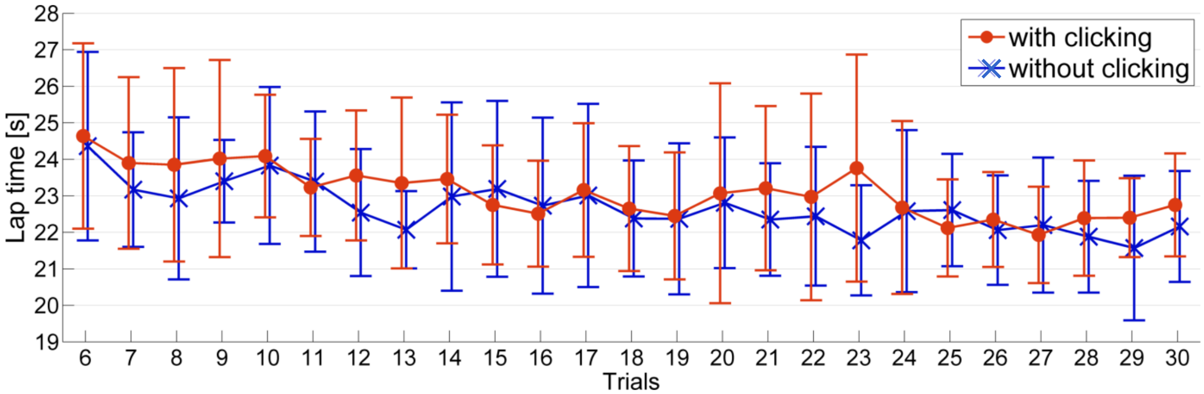

Figure 3: Average lap time for each trial.

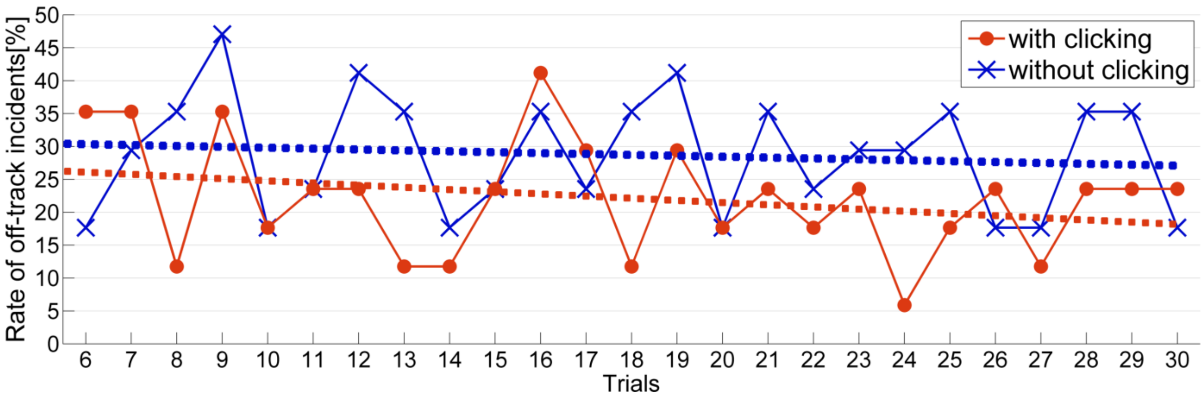

Figure 4: Rate of off-track incidents.

Eventually, data for 17 participants (13 males and four females) in the with-feedback group and 17 participants (11 males and six females) in the without-feedback group were analyzed. Data for the first five trials were omitted since the trials were considered practice.

5.1 Lap time

Figure 3 shows the average lap time for all participants against the trial number. The mean lap time for all 25 trials was 23.046 s (S.D. 1.53 s) with feedback and 22.879 s (S.D. 1.72 s) without feedback. A t-test found no significant difference ($t(16) = 0.31$, $p = 0.75$, n.s.). This result means that the clicking feedback had little effect on the lap time of the driving.

5.2 Rate of off-track incidents

Figure 4 shows the rates of off-track incidents. A t-test revealed that there are significant differences ($t(16) = 3.60$, $p < 0.05$) between the feedback conditions. We also applied linear-fitting (dashed line) for each feedback condition. In general, exponential fitting is used for a learning curve, but we chose a simpler approach in this case to compare the two lines statistically. To test the parallelism of the lines, we performed a one-way analysis of variance (ANOVA). This analysis did not find a significant difference in the gradient of the lines ($F(1,46) = 0.307$, $MSe = 80.0$, n.s.). In contrast to our expectation, the two linear-fitting lines are parallel with each other, showing that the clicking feedback does not affect learning. However, an analysis of covariance (ANCOVA) found a significant difference in the intercept ($F(2,47) = 4.335$, $p < 0.05$). This result suggests that the rate of off-track incidents was significantly reduced by the clicking feedback. Hence, the clicking feedback was considered to promote safer driving.

5.3 Controllability evaluation

After all trials were completed, the participants were asked to evaluate the clicking feedback, in terms of whether the clicking feedback made the control easier, on a five-point scale (1: more difficult, 3: the same under the two conditions, 5: easier) as shown in Table 1. Participants were classified into four groups depending on the driving skill that they claimed to have before the experiment, and two groups depending on whether the main trials were with/without feedback. As noted at the end of section 4.2, all participants experienced both conditions so that they could compare the two.

Table 1: Controllability evaluation of clicking feedback. Both group A and B evaluated how easy the control was when they drove under the with-feedback condition, compare with the without-feedback condition

Confidence in driving skill	Group A	Group B	Average
Confident	3.38	3.33	3.36
Not that confident	3.00	4.67	3.83
Sunday driver	2.80	4.25	3.44
No driver’s license	3.20	3.75	3.54
Average	3.14	3.86	3.50

We applied a two-way ANOVA for the order of the feedback condition (i.e. Group A tested under the with-feedback condition first, while group B tested under the without-feedback condition first, as explained in 4.2) and the confidence in driving. This analysis demonstrated a marginally significant difference between the feedback conditions ($F(1,33) = 3.07$, $MSe = 1.22$, $p < 0.10$), but not between the confidence in driving ($F(1,33) = 0.08$, n.s) and the two-factor interaction ($F(1,33) = 1.40$, n.s).

Concerning the order of the feedback condition, the participants of group A, who experienced the main trials without the clicking feedback, evaluated the controllability of the feedback higher than those in the main trials with the feedback. It seems that the participants of group B, who experienced the main trials with the feedback, felt liberated in the additional trials without feedback, and they therefore evaluated the feedback less favorably.

The overall average of the evaluation of 3.50 suggests that the clicking feedback improved the controllability of the accelerator pedal. This effect would apply to all drivers who were already accustomed to or unfamiliar with the driving environment. They supposedly perceived the clicking feedback as an additional tactile cue with which to support their control of the accelerator pedal.

5.4 Impression of the clicking feedback

The participants were also asked to freely state their impressions of the feedback. Table 2 categorizes the answers, dividing the participants into two groups: those in the main trials under the with-feedback condition (group A) and without-feedback condition (group B). The table shows that the number of positive answers stating that “the clicking feedback made the pedal easier to grasp the pedal position” (17 participants) was the largest, followed by “I felt like I was pushing more than I really was” and “I concentrated more on the control”. These positive answers indicate that the feedback is effective for safer driving. A negative comment was that the clicking feedback was irritating (seven participants; three participants from the confident group, one from the not-that-confident group and three from the no-driver’s-license group).

Table 2: Impression of clicking feedback.

<table>
<tr><th>Impression of the clicking feedback</th><th>Group A</th><th>Group B</th><th>Sub-total</th><th>Total</th></tr>
<tr><td>Easy to grasp the position</td><td>8</td><td>9</td><td>17</td><td rowspan="5">29</td></tr>
<tr><td>I felt like I was pushing more than I really was</td><td>1</td><td>4</td><td>5</td></tr>
<tr><td>I concentrated more on the control</td><td>0</td><td>3</td><td>3</td></tr>
<tr><td>I was more careful</td><td>0</td><td>2</td><td>2</td></tr>
<tr><td>Comfortable</td><td>1</td><td>1</td><td>2</td></tr>
<tr><td>Irritating</td><td>4</td><td>3</td><td>7</td><td>7</td></tr>
</table>

In addition to the comments listed in Table 2, interesting comments were “I felt as if there was some physical counterforce” and “I suppose that the pedal was locked at the clicking positions”, each stated by a single participant. Although no physical force was generated and mere vibration was presented in our experiment, the participants seemed to have felt a force. The decaying sinusoidal vibration that we employed is known to induce an illusory kinesthetic sense [19]. This illusion is attributed to the fact that the vibration simulates the skin friction resulting from pressure. We speculate that a similar phenomenon occurred in the experiment.

6 EXPERIMENT 2: OPTIMIZATION OF RESOLUTION

The first experiment verified our hypothesis that the periodic clicking feedback could enhance the accelerator pedal control, but the stimulation parameters were not optimized. Thus, in the second experiment, we focused on the optimization of one important stimulation parameter, the resolution of the clicking feedback, which was fixed to five in the previous experiment.

The other concern with the first experiment was the instruction provided to the participants. We asked them to drive as quickly as they could, but this did not relate well to the situation of daily driving. Therefore, we also changed the experimental instruction to a safe driving task that is closer than the time trial to real-life driving. Furthermore, to determine the occurrence probability of the illusory kinesthetic sense generated by clicking feedback, we asked all participants whether they felt a kinesthetic sense when the clicking feedback was presented.

6.1 Experimental conditions

We used the setup of the previous experiment, except for the number of divisions in the clicking feedback. Because more than nine clicks (i.e., dividing the pedal’s range of movement into 10 segments) seemed to be perceived as continuous vibration that is uncountable, and less than three clicks was not effective as periodic feedback, we compared four conditions: three, five, seven and nine clicks.

The trial was one lap of driving as in the previous experiment. The trial was repeated three times in this experiment. We employed 40 participants aged between 17 and 37 years, none of who had participated in the previous experiment. The participants were classified into four groups according to their driving skill as in the previous experiment. The experimenter assigned one of the four resolution conditions for each participant.

6.2 Experimental procedures

Before the first trial, the participants were asked to strictly avoid off-track incidents and drive safely as they would when driving for real, but to complete the lap within 45 seconds. We considered that this time limit would prevent stop-and-go driving, while allowing drivers to drive safety without rushing.

In the first trial, all the participants drove under the without-feedback condition. This trial was regarded as a practice and removed from later analysis. In the second trial, half of the participants drove under the with-feedback condition (group A) and the rest under the without-feedback condition (group B). The third trial was conducted under the opposite condition of the second trial. The experimenter recorded the lap time and the number of off-track incidents.

After the three trials, the experimenter asked the participants three questions. (1) “Did the clicking feedback make it easier to grasp the position of the accelerator pedal?” (2) “Did the clicking feedback make the accelerator easier to control?” (3) “Did you feel a counterforce when the clicking feedback was presented?” The participants answered between 0 and 100 (100: easier, 50: the same in the two conditions, 0: more difficult) for question (1) and (2), and yes or no for question (3).

7 EXPERIMENT 2: RESULTS AND DISCUSSIONS

7.1 Lap time and rate of off-track incidents

All the participants finished the trial within 45 seconds. We performed a one-way ANOVA using the lap time for each resolution condition. This analysis did not find a significant difference ($F(3,32) = 0.9$, $MSe = 21.086$, n.s.) in the number of divisions in the feedback. This agrees with the result of the previous experiment, which revealed no significance between the five-click feedback condition and the without-feedback condition.

There were off-track incidents in 6.25% of the 80 trials (40 participants × 2 feedback conditions × 1 trial each); this rate was clearly low compared with that of the previous experiment (26.47%). We consider that the experimental driving task was closer than the task in the previous experiment to real driving, owing to the instructions given.

7.2 Grasping the position

All the evaluation scores for the grasping of position were higher than 70 points, as shown in Figure 5. The average score overall was 80.0 points. The participants provided with seven-click feedback scored the highest value of 86.0 points, but a one-way ANOVA did not find a significant difference among the feedback resolutions for the grasping of position ($F(3,36) = 0.51$, $MSe = 479.4$, n.s.).

7.3 Controllability

All the scores for controllability were higher than 65 points, and the overall average was 67.9 points. The highest value of 74.0 was achieved by the participants of the nine-click-feedback group, but a one-way ANOVA did not find a significant effect of the resolution of the clicking feedback on controllability by ($F(3,36)$ = 0.20, $MSe = 850.9$, n.s.).

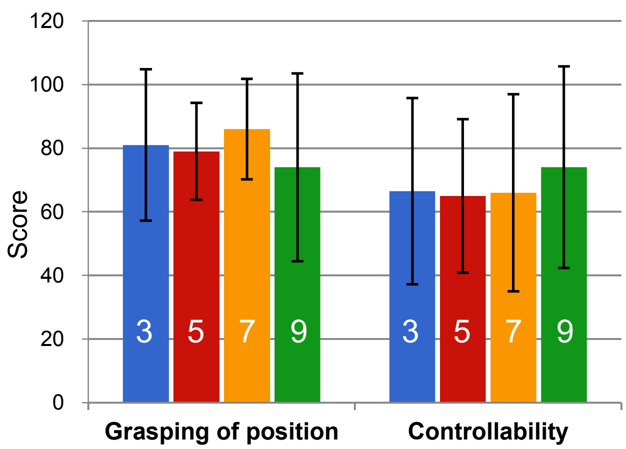

Figure 5: Evaluation of grasping of position and controllability (100: easier, 50: the same in the two conditions, 0: more difficult). Error bars indicate the standard division.

Summarizing the results for the grasping of position and controllability, we found that when the number of clicks was from three to nine, the clicking feedback was almost evenly effective. Additionally, analysis showed a moderate correlation ($R^2 = 0.28$, $p < 0.001$) between the grasping of position and controllability, implying that our approach to make it easier to grasp the position of the accelerator pedal can improve the controllability of acceleration.

7.4 Illusory kinesthetic sense

Table 3 shows the ratio of the participants who felt a counterforce when the clicking feedback was presented. More than half of the participants felt the illusory kinesthetic sense under all resolution conditions. Especially, under the five-click-resolution condition, 80% of the participants (8 of 10 participants) stated that they felt the force, although an a priori comparison using the Tukey-Kramer test showed that it was no statistically significant different among resolutions.

Overall, 65% of participants felt a force due to the decaying sinusoidal vibration. The technique of illusory force representation could be used to virtually alter the heaviness of the pedal according to the driving situation, without redesigning the mechanical structure of the pedal.

Table 3: Occurrence ratio of the illusory kinesthetic sense.

Resolution	3	5	7	9	Total
Ratio	60%	80%	70%	50%	65%

8 Conclusions and Future Work

This paper proposed a novel method with which to improve the control of the accelerator pedal by applying feedback in the form of a periodic click-like feeling as an additional tactile cue. In a first verification experiment with a driving simulator and five-click feedback, the rate of off-track incidents decreased. A questionnaire revealed that the pedal's position was easily grasped owing to the clicking feedback. The controllability was also improved by incorporating the clicking feedback regardless of the driver's skill. In a second experiment to optimize the resolution of the feedback, there were no significant differences among the resolutions, and the evaluation of grasping the position of the accelerator pedal and controllability improved evenly for all resolutions, compared with the without-feedback condition. An interesting finding was that the clicking feedback could generate in illusory kinesthetic sense even though feedback was a mere vibration and could not generate a force.

There are several possible future works. One is to change the condition of the experiment. In our current setup, the participants drove while wearing only socks on their feet, which is not comparable to the real case of a driver wearing shoes in a real car. An experiment with shoes may provide insights into the practical use of the system. Prior works on vibrotactile floor displays, in which the ground surface, such as gravel or snow, is virtually altered [20], found that the vibrotactile stimulus simulating the material property could be conveyed though shoes. We trialed our clicking feedback pedal with the user wearing shoes, and found that although the perceived tactile stimulus was weaker, it was certainly perceived.

Another future work is to find an optimal stimulation. For example, the waveform as well as the resolution can be optimized, or the tactile feedback might be related not only to the position of the pedal but also to the speed or force of the pedal input. Discussion of an optimal stimulation would also include the use of tactile feedback for not only the accelerator pedal but also the brake pedal and steering wheel.

References

[1] J. R. Lishman and D. N. Lee, The autonomy of visual kinaesthesis. *Perception*, 2(3): 287-294, 1973.

[2] Y. Kurihara, Y. Kuniyasu, T. Hachisu, M. Sato, S. Fukushima and H. Kajimoto. Augmentation of Kinesthetic Sensation by Adding "Rotary Switch Feeling" Feedback. *Proceedings of third Augmented Human International Conference* (Megève, France, March 8-9, 2012).

[3] M. Badescu, C. Wampler, and C. Mavroidis. Rotary haptic knob for vehicular instrument controls. *Proceedings of 10th Symposium on Haptic Interfaces for Virtual Environment and Teleoperator Systems* (HAPTICS'02, Orlando, FL, March 24-25, 2002), pages 342-343.

[4] O. M. J. Carsten and F. N. Tate: Intelligent speed adaptation: accident savings and cost–benefit analysis. *Accident Analysis & Prevention,* 37(4):407-416, 2005.

[5] P. A. Ioannou and C. C. Chien. Autonomous intelligent cruise control. *Proceedings of IEEE Transactions on Vehicular Technology,* 42(4):657-672, 1993.

[6] V. Ardalan and E. Azim. Research Advances in Intelligent Collision Avoidance and Adaptive Cruise Control. *Proceedings of IEEE Transactions on Intelligent Transportation Systems*, 4(3):143-153, 2003.

[7] K. Suzuki and H. Jansson. An analysis of driver's steering behavior during auditory or haptic warnings for the designing of lane departure warning system. *The Japanese Society of Automotive Engineers (JSAE) Review,* 24(1):65-70, 2003.

[8] J. D. Lee, J. D. Hoffman and E. Hayes. Collision warning design to mitigate driver distraction. *Proceedings of the SIGCHI conference on Human factors in computing systems* (CHI'04, Vienna, Austria, April 24-29, 2004), pages 65-72.

[9] J. B. F. Van Erp and H. A. H. C. Van Veen. Vibrotactile in-vehicle navigation system. *Transportation Research Part F: Traffic Psychology and Behaviour*, 7(4-5):247-256, 2004.

[10] H. Z. Tan, R. Gray and J. J. Young. A haptic back display for attentional and directional cueing. *The Electronic Journal of Haptics Research (Haptics-e),* 3(1), 2003.

[11] Nissan Motor Co., Ltd., Intelligent cruise control. http://www.nissan-global.com/EN/DOCUMENT/PDF/TECHNOLOGY/TECHNICAL/intelligent_en.pdf (accessed on October 29, 2012)

[12] Continental Automotive, Active force feedback pedal (AFFP). http://www.conti-online.com/generator/www/de/en/continental/automotive/themes/passenger_cars/chassis_safety/chassis_components/fahrwerkselektronik/fahrwerkselektronik_en.html (accessed on October 29, 2012)

[13] L. B. Rosenberg. Virtual fixtures: perceptual tools for telerobotic manipulation. *Proceedings of Virtual Reality Annual International Symposium* (Seattle, WA, September 18-22, 1993), pages 76-82.

[14] Y. Ochiai and K. Toyoshima. Invisible feet under the vehicle. *Proceedings of third Augmented Human International Conference* (Megève, France, March 8-9, 2012).

[15] A. Cassinelli, C. Reynolds and M. Ishikawa. Augmenting spatial awareness with Haptic Radar. *Proceedings of Tenth IEEE International Symposium on Wearable Computers* (ISWC'06, Montreux, Switzerland, October 11-14, 2006), pages 61-64.

[16] S. Saga, N. Kawakami and S. Tachi. Haptic teaching using opposite force presentation. *Proceedings of IEEE WorldHaptics Conference* (Pisa, Italy, March 18-20, 2005).

[17] A. M. Okamura, M. Cutkosky, and J. Dennerlein. Reality-based models for vibration feedback in virtual environments. *IEEE/ASME Transactions on Mechatronics*, 6(3):245-252, 2001.

[18] Sony Computer Entertainment, Inc., GRAN TURISMO, http://www.gran-turismo.com/ (accessed on October 1, 2012)

[19] M. Konyo, H. Yamada, S. Okamoto, and S. Tadokoro. Alternative display of friction represented by tactile stimulation without tangential force. *Haptics: Perception, Devices and Scenarios (Proceedings of EuroHaptics'08)*, 5024: 619-629, 2008.

[20] Y. Visell, A. Law and J. R. Cooperstock. Touch Is Everywhere: Floor Surfaces as Ambient Haptic Interfaces. *IEEE Transactions on Haptics,* 2(3): 148-159, 2009.