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Analyzing Headlight Flicker Patterns for Improving the Pedestrian Detectability from a Driver

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***Abstract*— In this paper, we analyze headlight flicker patterns which improve the pedestrian detectability from a driver. Recently, headlights are becoming capable of selectively projecting light on a pedestrian in addition to the normal forward projection. However, it is still not clear how the light should be projected to effectively improve the visibility of the pedestrian. We actually analyze nine flicker patterns by controlling duty ratios and durations of lighting time, and conduct experiments in field and laboratory settings. As a result, we reveal that a specific fundamental frequency is effective for improving the pedestrian detectability from a driver. We also conclude that the difference between the two settings are not significant.**

I. Introduction

Following recent advance in ITS technology, many kinds of ADAS (Advanced Driver-Assistance Systems) have been developed and the road traffic is becoming safer. However, there are still many fatal car accidents involving pedestrians. Such accidents often occur during night time. This is because pedestrians are barely visible and difficult to be found by drivers in dark. Figure 1 shows an example of a real traffic scene at night. A pedestrian exists in the center of the image, but we cannot find it easily because of low contrast, low intensity, and so on. If ADAS can improve the pedestrian detectability from a driver (hereafter, "pedestrian detectability"), we can expect that it will decrease the number of traffic accidents between cars and pedestrians.

Some existing systems warn the driver with the existence of pedestrians at night time. For example, a typical system detects pedestrians using an infrared camera or a depth sensor, and then notifies their existence to the driver by audio-visual means. However, the audio notification informs the driver only their existence but not their exact positions. On the other hand, the visual notification needs a display placed on the dashboard, so it could distract the driver's gaze, and cause a risky situation. In addition, both of them only notify the existence of pedestrians, but cannot improve their detectability.

Meanwhile, a headlight is an indispensable device that supports the driver's vision at night. Nowadays, headlight control technologies have been developed and are expected to be used as part of ADAS; A state-of-the-art headlight consists of many LEDs instead of an HID (High-Intensity Discharge) headlamp. Since the direction and the luminance of each LED can be controlled, it allows the headlight to illuminate a local area selectively in addition to the normal forward projection. It could be used to project light on a specific pedestrian in order to improve his/her detectability from the driver. Considering the usage of such technology, our scenario consists of three steps: Firstly, detecting pedestrians using an infrared camera, a depth sensor, and so on, using existing reliable methods. Secondly, selecting only pedestrians with low detectability from the driver to avoid distracting him/her from driving. Finally, projecting light on the selected pedestrians. Here, the light is projected on their bodies excluding their heads due to avoid dazzling them. Various methods for detecting pedestrians or estimating the pedestrian detectability have been proposed[1], [2], [3], [4]. Also, headlights which can project light on a target region is already commercialized[5], [6]. However, it is not clear what kind of light projection increases the pedestrian detectability effectively.

In this paper, we propose an effective light projection method which improves the pedestrian detectability. Although various kinds of light projections could be considered, such as flickering, changing color, texture, and so on, we focus on flicker based on psychophysical findings as shown in the bottom of Fig. 1 and analyze what kind of a flicker pattern is effective to improve the pedestrian detectability for a human driver.

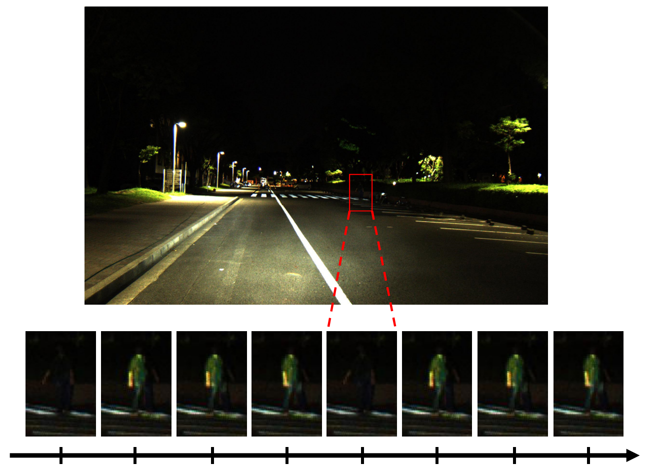

Fig. 1. Example of a real traffic scene at night. A pedestrian exists in the center of the image. The bottom shows a flicker pattern of light projection on the pedestrian to improve his/her detectability from a driver.

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First, we conduct an experiment in a field setting to analyze in a practical situation. After that, we conduct an experiment in a laboratory setting to analyze the differences from the field setting in order to confirm the feasibility of a larger-scale offline experiment.

Our contributions are as follows:

1) Reveal an effective flicker pattern for improving the pedestrian detectability: We measure the pedestrian detectability for various flicker patterns through an experiment for this.
2) Confirm the feasibility of experiments in a laboratory setting: We conduct experiments in both field and laboratory settings and analyze the difference for this.

The rest of the paper is organized as follows: Section II introduces related works. Then, section III describes flicker patterns that we consider. Next, experiments and their results are reported in section IV, and we discuss the results in section V. Finally, we conclude this paper in section VI.

II. Related works

In this paper, we define the pedestrian detectability as "the degree of easiness to perceive a pedestrian or recognize his/her existence from a driver". As a similar measure, saliency is well known. We assume that the findings in the research on saliency can be applied to our work.

A saliency is defined as "the degree for easiness of drawing our visual attention to a region"[7]. Various models to estimate the saliency in each region (saliency map) have been proposed. They can be classified into two types: bottom-up models and top-down models[7]. The bottom-up models basically calculate saliency using information only extracted from images. Itti et al. proposed a typical model to estimate the saliency using three visual features: intensity, color, and orientation in a region[8]. They have also proposed many advanced models[7]. For example, two additional features: flicker and motion, were introduced to estimate the saliency map of a dynamic scene[9]. On the other hand, the top-down models attempt to incorporate additional cues such as prior knowledge on objects, human intention, and cognitive states in a task. Some researchers proposed top-down models considering influence of difference in visual features between a search target and distractors[10], [11], [12]. Pedestrian detectability is affected by such additional cues, especially prior knowledge on a pedestrian.

While saliency is measured under free viewing or a given task, the pedestrian detectability is always measured under a pedestrian recognition task and different tasks may attract visual attention in different ways. To the best of our knowledge, there is no method to improve the pedestrian detectability. In the research field of saliency, Takimoto et al. proposed a method to improve saliency by color modulation[13] that changes the color of a selected region in an image. They confirmed that the viewers' attention was attracted to the region through an experiment. However, in the dark, humans can hardly discriminate colors because cone cells do not work. For this reason, it is expected that changing a color is not effective to improve the pedestrian detectability at night. In contrast, since rod cells work dominantly in the dark, sensitivity to light increases. As mentioned above, the feature of flicker has been introduced to estimate the saliency as a dynamic feature [9]. In other word, a flickering light draws visual attention. We therefore consider projecting flickering light on a pedestrian with low visibility at night to improve his/her pedestrian detectability. In this paper, we analyze an effective flicker pattern.

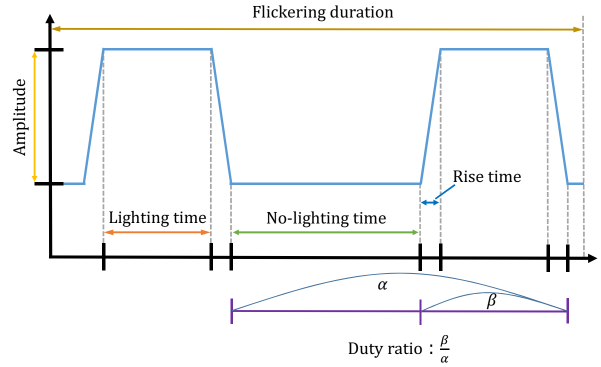

Fig. 2. Parameters of a flicker pattern.

TABLE I
Nine flicker patterns considered in the experiments.

		Lighting time [sec.]			
		0.125	0.250	0.500	1.000
Duty ratio	0.250	✓	✓		
	0.500	✓	✓	✓	
	0.750		✓	✓	✓
	1.000				✓

III. Flicker patterns

Various flicker patterns can be generated using several parameters. Figure 2 shows the parameters: lighting time, no-lighting time, duty ratio, rise time, flickering duration, amplitude, and frequency.

In the case of the same intensity difference, shorter rising time yields higher saliency according to the principle of saliency computation. Therefore, we employ a wave with a specific shape whose rise time is zero, i.e. square wave.

Among other parameters, we use duty ratio and lighting time since they are easy to control. By adjusting these parameters, the other parameters such as non-lighting time and frequency could be automatically decided.

We consider twelve flicker patterns generated by a combination of three duty ratios (0.250, 0.500, and 0.750) and four duration of lighting times (0.125 sec., 0.250 sec., 0.500 sec., and 1.000 sec.). From the flicker patterns, we exclude extremely slow flicker patterns and fast flicker patterns. In addition, we add a non-flicker pattern without no-lighting time (duty ratio: 1.000) in order to confirm the effectiveness of the flicker. Table I shows the nine flicker patterns we consider.

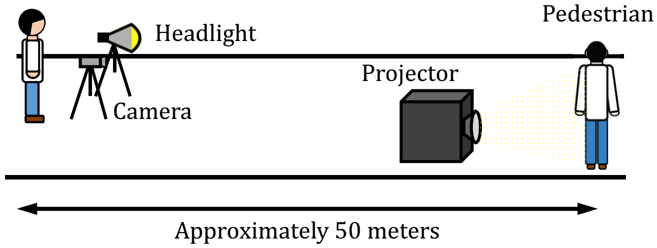

Fig. 3. Schematic diagram of the experimental environment in the field setting.

IV. Experiments

A. Purpose

We first conduct an experiment in a field setting in order to analyze an effective flicker pattern for improving the pedestrian detectability. However, since the experiment in the field setting imposes a huge cost, we wish to conduct a larger-scale offline experiment in the future. In order to confirm the feasibility for this, we also conduct an experiment in a laboratory setting and analyze the difference from the field setting.

B. Experiment in the Field Setting

1) Dataset: Since headlights which can control and project light on a pedestrian is not commercialized yet, we used a high luminance projector[1]. After detecting the pedestrian by a depth sensor[2], white light was projected from the projector to the body of a pedestrian excluding his/her head. The participants subjectively evaluated the pedestrian detectability for the nine patterns of flicker shown in Table I.

2) Environment: Figure 3 shows the schematic diagram of the experimental environment in the field setting. The pedestrian stood 50 meters away from participants and a projector was set near the pedestrian. The experiment was conducted on a road in Nagoya University's Higashiyama campus, where there was no distractor that extremely drew the participants' visual attention to the background. An ordinary headlight[3] was placed in front of the participants and projected a common low-beam forward. Each experiment was conducted for several participants sitting on a chair behind the headlight at the same time. During the experiment, we recorded the scene using a video camera[4] set in front of the participants to prepare videos used for the experiment in the laboratory setting. Figures 4 and 5 show a frame during no-lighting time and lighting time in the video, respectively.

3) Procedure: The participants observed a pair of flicker patterns one by one. Then, they were asked to select a pattern which they felt easier to perceive the pedestrians in a traffic situation. Nine male students in their twenties with a driver's license participated in the experiment. The detailed procedure is as follows:

[1]Sony VPL-FX37 Projector. Effective light flux 6,000 lm.
[2]Microsoft Kinect for Xbox 360.
[3]IPF 341HLB. 2,800 lm. Color temperature 6,500K.
[4]FLIR Systems Grasshopper3. It can record a color image of 1,920 × 1,440 pixels resolution at 26 fps.

Fig. 4. Frame during no-lighting time. A pedestrian exists in the red rectangle.

Fig. 5. Frame during lighting time. A pedestrian exists in the red rectangle.

1) The experimenter projects the light with a flicker pattern on the pedestrian for a few seconds.
2) No light is projected on the pedestrian for a few seconds.
3) The experimenter projects the light with another flicker pattern on the pedestrian for a few seconds.
4) The participants evaluate the flicker patterns (select between 1) and 3)).

In Step 2), we took an interval of a few seconds in order to reduce effects of persistence of the previous flicker pattern. We assigned the participants with the above trial for 36 ($= {}_9C_2$) pairs of flicker pattens. Both the order of presentation in the pair and the order of pairs were random. The participants observed each pair of flicker patterns in a trial only once.

C. Experiment in the Laboratory Setting

1) Dataset: As mentioned in Section IV-B-2), we recorded the scenes using the video camera set in front of the participants during the experiment in the field setting. We clipped four seconds of the video recording for each flicker pattern for evaluation in the laboratory setting.

2) Environment: Figure 6 shows a setup that we implemented to simulate the dark environment. During the

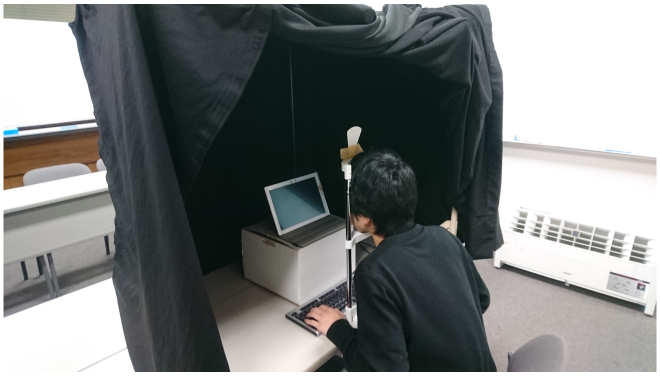

Fig. 6. Experimental setup in the laboratory setting. During the experiment, the devices and the participant were covered with a black curtain.

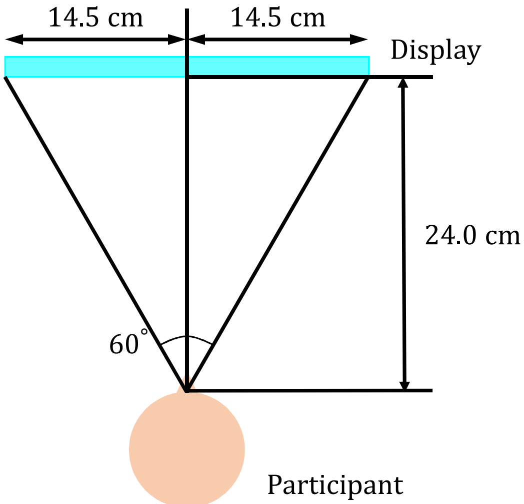

Fig. 7. Position of the display from a participant.

Fig. 8. GUI used in the laboratory setting experiment.

experiment, we covered the devices and the participant with a blackout curtain to shut out external light. Figure 7 shows the positional relationship between a participant and a tablet PC[5] for displaying the video. The tablet PC had an organic electro-luminescence display that could realize high contrast ratio and high black reproducibility, suitable for reproducing a dark environment.

3) Procedure: We asked the participants to observe a pair of videos that recorded different flicker patterns one by one. Then, they were asked to select a video which they felt easier to perceive the pedestrian in a traffic scene. Participants were the same as those who participated in the experiment in the field setting. Note that the scenes of the videos which the participants evaluated in this experiment were the same as those they actually observed in the field setting but not scenes the other participants observed. This restriction was set since main purpose of the experiment in the laboratory setting was to analyze the difference from the field setting. The detailed procedure is as follows:

1) A participant is informed of the approximate position of the pedestrian who exists in the frames and arbitrarily selects one of the paired videos for the observation using a GUI shown in Fig. 8.
2) The experimenter presents a video containing only noise for one second.
3) The experimenter presents the selected video for four seconds.
4) The experimenter presents the video containing only noise again.
5) The participant selects one of the paired videos as with Step 1).
6) By repeating Steps 2) to 5), the participant observes both of the videos and evaluates the flicker patterns.
7) The participant could decide the order to play the videos and could replay as many times as he wishes. Note that in the field setting, the order could not be decided by each participant and he only observed each pair of flicker patterns only once.

In Steps 2) and 4), a video containing only noise before and after presenting the videos of flicker patterns was presented to reduce the influence of persistence of vision. There were 36 ($= {}_9C_2$) pairs of videos in total and the presentation order of the 36 pairs was random. Participants could only decide the order of observing the paired videos.

D. Detectability Measurement

It is difficult to calculate the pedestrian detectability as a physical quantity since it is measured based on human sense as mentioned in Section II. Here, we applied Thurstone's paired comparison method[14] to quantify the detectability with an interval scale. This is one of the sensory evaluation methods, which is capable of measuring subjective differences among multiple samples based on evaluations of paired comparisons. It also seems to give less burden to the participants than the others of the like since it does not require the evaluation of the same pairs multiple times.

E. Results

Figures 9 and 10 show the results in each setting. Here, we quantified the detectability with a degree ranging from zero to one. In both settings, higher duty ratio yielded higher detectability for the same lighting time. Also, shorter lighting

[5]Samsung Electronics Galaxy TabPro S. Contrast ratio 10,000:1.

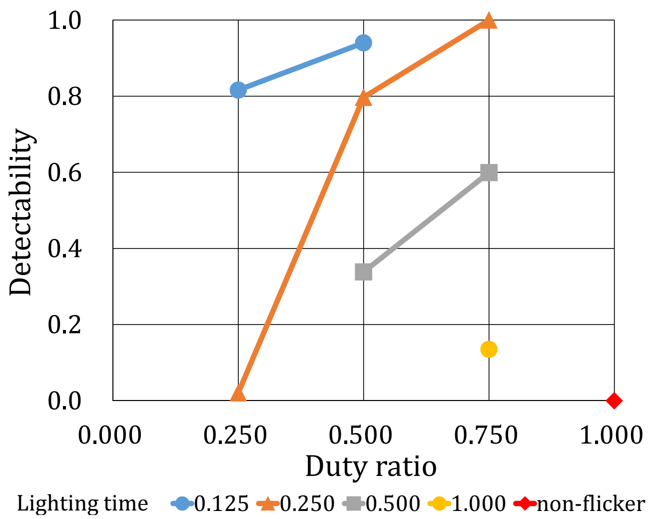

Fig. 9. Relation between flicker patterns and detectability in the field setting.

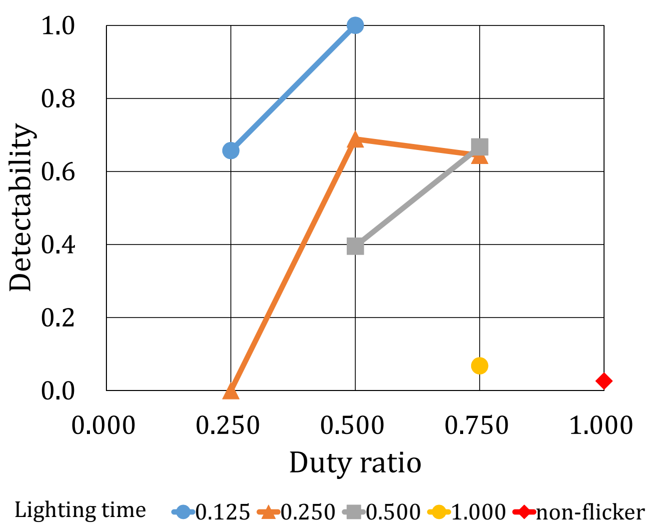

Fig. 10. Relation between flicker patterns and detectability in the laboratory setting.

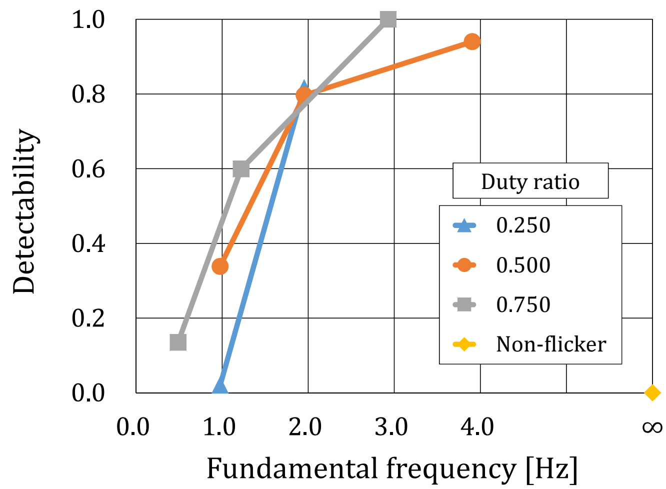

Fig. 11. Relation between flicker patterns represented by the fundamental frequency and detectability in the field setting.

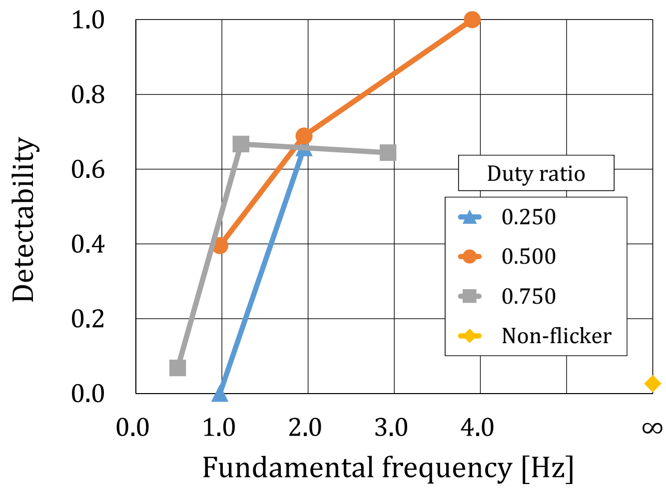

Fig. 12. Relation between flicker patterns represented by the fundamental frequency and detectability in the laboratory setting.

time yielded higher detectability for the same duty ratio. We confirmed that the pedestrian detectability for flicker projection does not depend only on the duty ratio. Also, the non-flicker pattern (duty ratio: 1.000) had lower detectability. This suggests that any flicker pattern is basically more effective than the non-flicker pattern.

Next, let's focus on the fundamental frequency as the representative factor of temporal characteristics of the flicker patterns. In order to obtain the fundamental frequency of each flicker pattern, Fourier transform is applied to the waveform of the flicker pattern, and the frequency at the first peak is taken. Figures 11 and 12 show the results analyzed by fundamental frequency in each setting. In the field setting, the highest detectability was obtained by the flicker pattern whose duty ratio was 0.750 and fundamental frequency was approximately 3 Hz. On the other hand, the highest detectability was obtained by the flicker pattern whose duty ratio was 0.500 and fundamental frequency was approximately 4 Hz in the laboratory setting.

V. Discussion

From Figures 11 and 12, we can confirm that the results in the field setting are similar to those in the laboratory setting. In both settings, flicker patterns basically had higher detectability than the non-flicker pattern. This shows the effectiveness of flicker projection. Also, we can see a tendency that the detectability improved as the frequency increased. On the other hand, humans cannot perceive flickers with a frequency higher than the Critical Fusion Frequency (CFF). We therefore assume that there is a peak of detectability between 4 Hz and the CFF. In order to confirm this, we will need to conduct an additional experiment using flicker patterns with higher frequency than we considered here.

On the other hand, the flicker pattern that yielded the highest detectability in the field setting whose duty ratio was 0.750 and fundamental frequency was 3 Hz, was different from that in the laboratory setting whose duty ratio was 0.500 and fundamental frequency was 4 Hz. The lighting time and the no-lighting time of the former were 0.125 and 0.042 seconds, respectively. Since the no-lighting time was very short, the former pattern may have appeared like the non-flicker pattern in the laboratory setting due to the display and the camera specifications. In fact, the detectability of the flicker pattern whose duty ratio was 0.750 and fundamental frequency was 3 Hz in the laboratory setting was not so high. In contrast, both of the lighting time and the no-lighting time of the latter were 0.125. The detectability was close to that of the same flicker pattern in the field setting. Since the no-lighting time was longer than the former, the detectability was probably not affected by the display and camera specifications.

Also, there are subtle differences between the results shown in Figures 11 and 12. We consider that the difference in the number of observing flicker patterns in each setting caused them; Each pair of flicker patterns was observed only once in the field setting, while it was allowed to be observed multiple times in the laboratory setting. As a result, participants would evaluate intuitively the patterns in the field setting, while they would examine and carefully select in the laboratory setting. If we wished to measure the physical reaction to a flicker as a different evaluation for detectability, we should allow the participants not to observe the same flicker pattern multiple times.

Although there are some differences as above, we still conclude that similar results were yielded in both settings. This frees us from conducting numerous experiments in the field setting which imposes a huge cost and allow as to perform larger-scale offline experiments in the laboratory.

VI. Conclusion

In this paper, we revealed an effective flicker pattern which improves pedestrian detectability in a real environments and analyzed the effect caused by the difference in experimental settings. Flicker patterns whose fundamental frequency was between 3 and 4 Hz showed the highest detectability, and as a whole, similar results were yielded in both field and laboratory settings.

In the future, we will evaluate the pedestrian detectability of flicker patterns with higher frequency, with a combination of multiple duty ratios, or other patterns by changing different visual features such as texture, color, and so on. We also considered only a traffic scene without other significantly attractive objects that draw the visual attention around the pedestrian and also with a fixed participant's position. We will consider the effect of such conditions not considered in the experiments introduced in this paper. Furthermore, we need to study the problems caused by projecting the flickering light on pedestrians from multiple vehicles.

Acknowledgment

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