

Smart Lighting for Enhancing Perception of Pedestrians based on Visual Properties

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ABSTRACT

We investigated a lighting method that supports pedestrian perception by vehicle drivers. This lighting method makes active use of visual characteristics such as the spatio-temporal frequency of contrast sensitivity. Using reasonable parameter values derived from preliminary experiments using a Campbell-Robson chart, we determined a suitable lighting pattern that improves the driver's pedestrian perception. In order to assess the influence of visual characteristics on a reaction-time-dependent task, such as pedestrian perception in nighttime, tests were performed in the target environment, the results of which validated the proposed method.

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INTRODUCTION

According to the traffic statistics compiled by the National Police Agency in Japan for 2014, fatalities due to traffic accidents have decreased for 14 consecutive years. The total number of fatalities in 2014 was 4,113, and approximately one-third of all traffic accident fatalities were pedestrians [1]. Analysis of traffic accident statistics revealed that approximately 70% of fatal accidents occurred at night. Moreover, 70% of fatal accidents that occur at nighttime involve pedestrians at crossing, which is also the largest category overall. Notably, nighttime accidents between a vehicle driving straight ahead and a crossing pedestrian are characterized by accidents in which the pedestrian is crossing from right to left (from the driver's perspective) occur at a high rate, 70%. Moreover, many fatal accidents occur at vehicle speeds ranging from 30 to 60 km/h. Based on the above considerations, countermeasures to prevent fatal accidents at night by quickly making drivers aware of potential safety hazards covering the foreword region for not only themselves but also those in opposite lanes are urgently needed [2] [3].

Therefore, in order to reduce the number of fatal nighttime accidents, driving support systems have been under continuous development. Such systems are designed to promote the early perception of pedestrians and coping behaviors by the vehicle driver to prevent accidents. Examples of such systems include adaptive front-lighting systems (AFSS), night view systems, and automatic high beam / adaptive driving beam (AHB/ADB) headlight systems [4] [5]. An AFS improves visibility by means of highly developed headlamps. A night view system is a cognitive support system for indirect view that

provides a warning to the driver through devices such as a head-up display or by voice sounds. Such a system incorporates sensors, such as cameras, that detect pedestrians [6] [7]. Finally, the development of the ADB system evolved from the improvement of AHB, which automatically controls the on/off state of headlight high beams, and ADB system is approaching commercial viability. The ADB system enables automatic high-beam deployment based on controlling the glare state with respect to both leading vehicles and oncoming vehicles. New functions are being developed thanks to innovations in headlight technology, such as the array shape of LEDs. For example, a spotlight function that can illuminate detected targets enables more warnings to be given to both drivers and pedestrians [8]. Moreover, using projectors for personal computers (PCs), headlights that can display high-resolution patterns in the actual target environment are also under development [9].

We have investigated a novel lighting method that can shorten the reaction time for the perception of pedestrians on a road. In particular, we focus on the ADB system in order to improve direct visibility. First, we measured the fundamental visual characteristics of drivers and analyzed the obtained data through preliminary experiments. Reasonable parameter values, such as the spatio-temporal frequency of high-contrast sensitivity, were determined. A target environment and an experimental scenario are designed based on the analysis results of traffic accident statistics. Based on the above, we developed a quantitative experimental evaluation method for automotive lighting [11] [12] [13].

In the present paper, we propose a suitable lighting pattern by which to improve the performance of a driver's pedestrian perception in order to shorten the driver's reaction time. Using the developed evaluation method and reasonable parameter values derived from preliminary experiments, we attempt to assess the influence of visual characteristics on a reaction-time-dependent task, such as pedestrian perception at night. Tests were performed to compare the designed lighting patterns with normal high beams in the target environment.

EXPERIMENTAL PROTOCOL

Design of the Experimental Scenario

An experimental scenario is designed to mimic a typical accidental scene, as shown in [Figure 1](#). The experimental scenario consists of the following two conditions: (1) the experimental vehicle travels in a straight line following a leading vehicle, and (2) the pedestrian attempts to walk across the road just after an oncoming vehicle passes the leading vehicle. We consider three typical positions at which the pedestrian appears: right side of the road, left side of the road, and center of the road. At each position, the pedestrian crosses toward the experimental vehicle's traffic lane. In particular, we consider the case in which a pedestrian in the center of the road crosses the experimental vehicle's lane immediately anterior to the experimental vehicle. Distance Y_p between the experimental vehicle and the pedestrian is 50 m. We defined this variable Y_p , because the high-beam cut-off distance is approximately 40 m. Low-beam headlights cannot directly illuminate a pedestrian who is 40 m away from the car. The road has a single 3 m-wide lane for each direction. The pedestrian on the roadside stands $d = 0.5$ m outside the roadway edge marking. Based on the above definitions, we obtain the following equations:

$$\frac{W - W_v + d}{Y_p} \leq \frac{V_{pL}}{V_0} \leq \frac{W + W_v + d}{Y_p} \quad (1)$$

$$\frac{W - W_v}{2Y_p} \leq \frac{V_{pC}}{V_0} \leq \frac{W + W_v}{2Y_p} \quad (2)$$

$$\frac{3W - W_v + d}{Y_p} \leq \frac{V_{pR}}{V_0} \leq \frac{3W + W_v + d}{Y_p} \quad (3)$$

where W_v is the vehicle width, V_0 is the vehicle speed, and V_{pL} , V_{pC} , and V_{pR} are the travel speeds of the pedestrians respectively. Collisions between the vehicle and the pedestrian are simulated using these equations. The collision vehicle moves at a speed of from 30 to 60 km/h, based on traffic accident statistics for night. The pedestrian crosses the street at a speed of from 2 to 6 km/h. [Figure 2](#) shows that a pedestrian crossing a road from the right (from the driver's perspective) has a high potential for being struck by a vehicle.

PROPOSED LIGHTING METHOD

Lighting Device and Experimental Overview

In this experiment, illumination of lighting patterns on road surface is controlled by two projectors in front of the experimental vehicle, as shown in [Figure 3](#). These projectors are customized using a commercial-type projector. Color filters are removed to guarantee the optical performance requirements of the general headlamps. As a result of this customization, the projectors have sharp optical peaks of luminous intensity at the center of the field angle. The luminance distribution is shown in [Figure 4](#). [Figure 4-\(a\)](#) and [4-\(b\)](#) show the vertical and horizontal luminance distributions, respectively. The dotted line in [Figure 4](#) shows the luminance distribution of the high beam, and the solid line shows the luminance distribution of the customized projector. We confirmed that the optical peak of the luminous intensity of the customized projectors is comparable to that of existing commonly used headlamps by experimental evaluation. Two customized projectors are installed in front of each headlamp of the experimental vehicle.

This projector system can simulate various lighting environments and can also control lighting patterns and draw flexible patterns in space in front of the vehicle. Several lighting methods have been designed to enhance drivers' perception of pedestrians. One such method is the direct illumination of pedestrians. Another is the indirect indication method of drawing patterns on the road. In the present paper, we focus on the direct illumination method because bumpy road surfaces can affect patterns displayed on the road. We focus on spatiotemporal frequency as the most fundamental visual characteristic.

That is to say, peripheral vision, gaze evoking, motion flow, and other factors are not considered herein. In the direct illumination method, we attempt to verify the effect of two lighting patterns: a blinking pattern and a grating pattern.

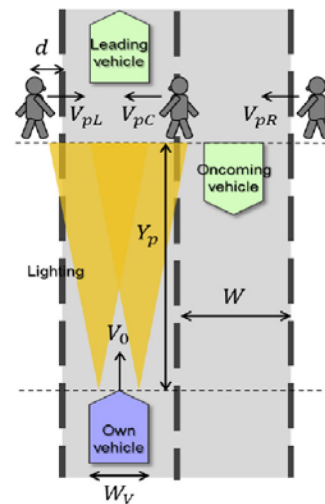


Figure 1. Experimental Scenario

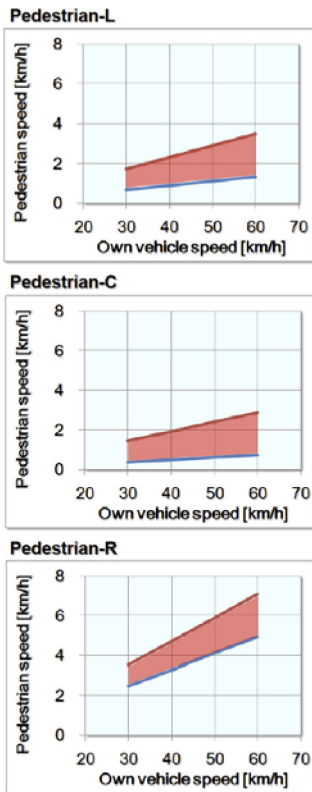
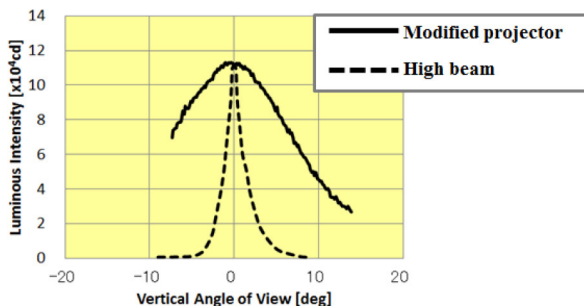


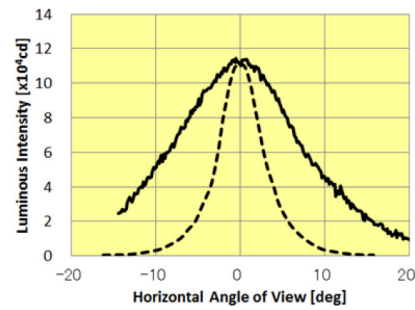
Figure 2. Estimation of Collision Timing



Figure 3. Experimental Vehicle



(a). Vertical



(b). Horizontal

Figure 4. Distribution of Luminous Intensity

Experimental Setup and Method

Figure 5 shows the experimental environment. In this experiment, all vehicles (the experimental vehicle, the leading vehicle, and the oncoming vehicle) remain parked under the left-hand driving regulation. The dummy pedestrian system shown in Figure 6 is set up to simulate the sudden appearance of a pedestrian on the road. The dummy pedestrian is a motor-controlled panel, and the timing of the appearance of the pedestrian and the illumination of the pedestrian can be synchronized. Thus, we can assign reaction time tasks to a driver upon perceiving a pedestrian for the purpose of reproducible measurement. The dummy pedestrian consists primarily of the panel and the motor, as shown in Figure 7. The panel has a life-sized printed picture of a pedestrian on a non-reflective paper background. The pedestrian is made to appear by rotating the panel by 90 degrees, as shown in Figure 8.

In the experiments of the present study, test participants sit in the driver's seat of the experimental vehicle, which remains parked on the road, and each participant must perform two tasks: (1) a pedestrian perception task, and (2) a driving simulation task, which simulates a normal driving load. These two tasks are performed in parallel throughout the experiment. Figure 9 shows the system used to simulate driving tasks. Five liquid crystal display devices are placed side by side on the trunk lid of the leading vehicle, which remains parked 50 m in front of the experimental vehicle. The leading target in the upper part of a screen is simulated based on actual driving logs. The goal steering angle must agree with steering angle commanded by the participant. As simulated driving tasks, the test participant performs position adjustment to bring the goal steering angle in line with the leading target.

The dummy pedestrians are located at three positions under the configuration shown in Figure 5. These positions are (A) left side of the road, (B) center of the road, and (C) right side of the road. Occasionally, a pedestrian appears 50 meters in front of the experimental vehicle. The timing of the pedestrian's appearance is accurately controlled by signals from a PC. Thus, the driver support lighting is performed simultaneously with the appearance of the dummy pedestrian. When the test participant in the experimental vehicle perceives the dummy pedestrian 50 meters ahead under the selected lighting pattern, the test participant indicates his/her perception by pressing a button attached to the steering wheel of the experimental vehicle. This allows the reaction time between the