Automotive Lighting Technology for Driver's Visibility Improvement using Imperceptible Pattern Illumination

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ABSTRACT

This paper introduces the driver's vision support concept using pixelated headlights with imperceptive pattern illumination for automotive lighting. Through the experiment, we confirmed that our projection does not harm visibility for the pedestrians and on-coming car driver's vision while the in-vehicle driver's visibility is enhanced. The practical enhancement algorithms for visibility are discussed with several projection results.

1 Introduction

A typical night vision system consists of an infrared camera and display device such as an LCD panel on the dashboard or a head-up display (HUD) in front of the windshield. HUDs display navigation information on the windshield and prevent drivers from being distracted from the road to check the displayed information. However, drivers need to be understanding that the correspondence between the displayed graphical information on an HUD and the actual road scene as viewed through the windshield. Hosseini et al. proposed an automotive augmented reality system for driver assistance that showed graphical information at the exact position according to the viewing position of drivers [1]. The system employed a full-windshield display with 3D position estimation using a stereo vision system. It enables a geometrically correct display for the driver's sight. Despite this precise alignment, the shift in viewpoint potentially causes misalignment of the annotation display. A pixelated headlight (PHL) was developed in recent years and enabled blocking high beams for oncoming vehicles and pedestrians [2]. It also enabled the display of turn arrows or other helpful graphics, such as a crosswalk on the roadway. Tambro et al. proposed improvements in visibility lighting during snowstorms [3].

The spatial augmented reality technology manipulates the appearance by using projectors or other optical display devices. Amano et al. [4] proposed the appearance manipulation technique with a projector-camera system. It enables the alternation of visible color or features in real-time and allows visual assistance for color vision disabilities and cataracts [5]. With this technique, we can

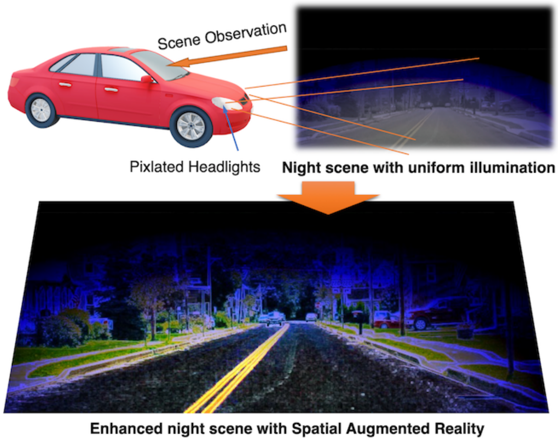


Fig. 1 Concept of vision support lighting

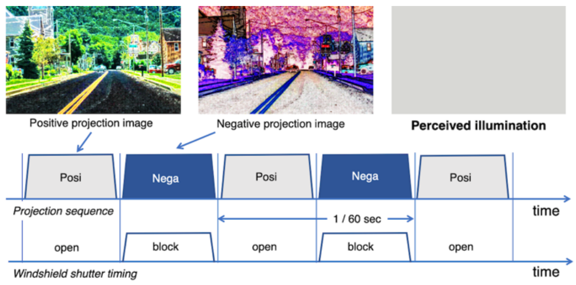


Fig. 2 Imperceptive pattern projection

expect the appearance manipulation installed on the PHL to enable head position-independent visual annotations without the complex mechanism shown in Fig.1. However, headlights have strict regulations by law in most countries that the bulbs must either be white or yellow (e.g., UK, EU, and most US states. Not allowed yellow in Japan since 2006). In addition to this, it potentially harms visibility for other cars or pedestrians. To address this regulation, we propose an imperceptible pattern projection technique for pedestrians or oncoming vehicles while the driver sees the enhanced scene through the windshield.

2 Imperceptible pattern in headlight illuminations

Imperceptible pattern projection has been proposed for 3D capturing in the virtual studio and other

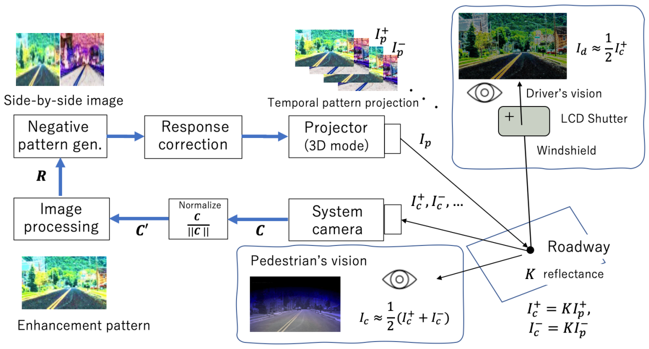


Fig. 3 Temporal coded projection system

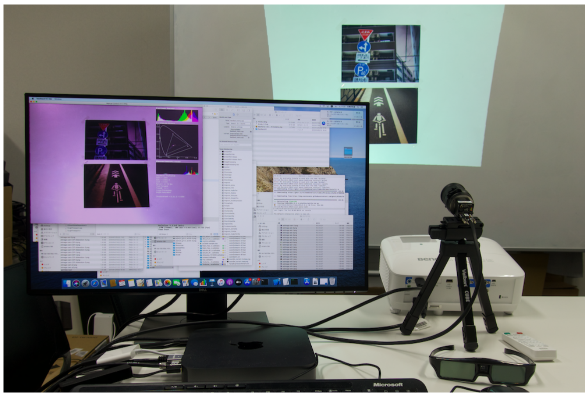


Fig. 4 Experimental setup

applications requiring continuous geometrical calibration [6]. We employ the imperceptible pattern projection technique for invisible pattern illumination for pedestrians or oncoming cars, as shown in Fig.2.

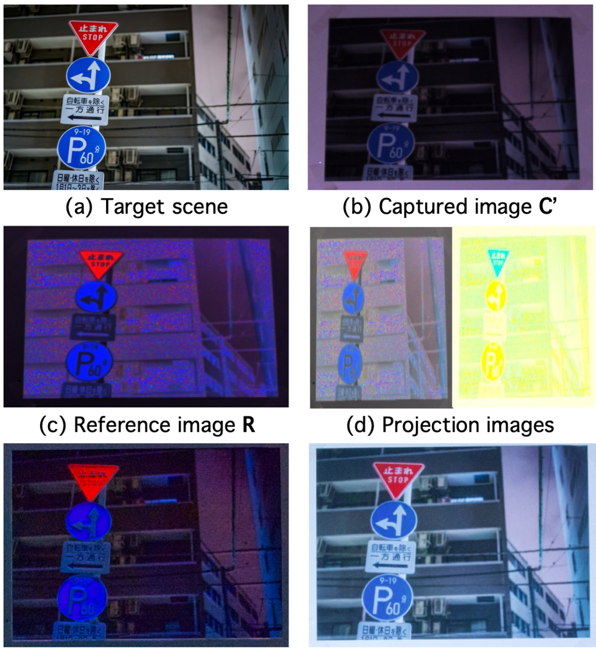
The system generates an enhancement illumination pattern (positive pattern) from a captured image with the on-vehicle camera and enhances a roadway scene with the illumination projection through the PHL. The next moment, our system generates an inverted illumination pattern (negative pattern) and projects to overwrap the positive illumination pattern on the roadway. These positive and negative patterns are rapidly alternated, then pedestrians or drivers in oncoming cars perceive it as illuminated with a white light for the mixing.

For a driver in the vehicle, the scene illuminated with negative projection is blocked by an elect-optical filter (e.g., LCD) installed in the windshield and perceives the enhanced scene with the positive pattern projection. We can use the 3D projection function employed by conventional projectors for its implementation.

3 Driver's vision enhancement with the projection

We implemented a proof-of-concept projection system shown in Fig.3. The system consists of a projector with a 3D projection function using LCD shutter glass (3D mode) and a conventional color camera (System camera). Both devices are attached to a system computer.

The system obtains the normalized captured image $\boldsymbol{C}'$ from roadway scene $\boldsymbol{C}$. Then, the system generates a projection pattern $\boldsymbol{R}$ for the scene enhancement by the desired image processing. Next, the system generates its inverted pattern as the negative projection pattern. These images are aligned in a side-by-side format. Then its image is converted to the projector image geometry with pixel mapping obtained by the geometrical calibration and sent to the projector after the radiometric compensation (It is a component-wise division by $\boldsymbol{C}'$ as estimated reflectance.) response correction. Lastly, pair images are projected with a temporary coding of I_p^+ for the first half-cycle and I_p^- for the last half-cycle using the 3D projection function.



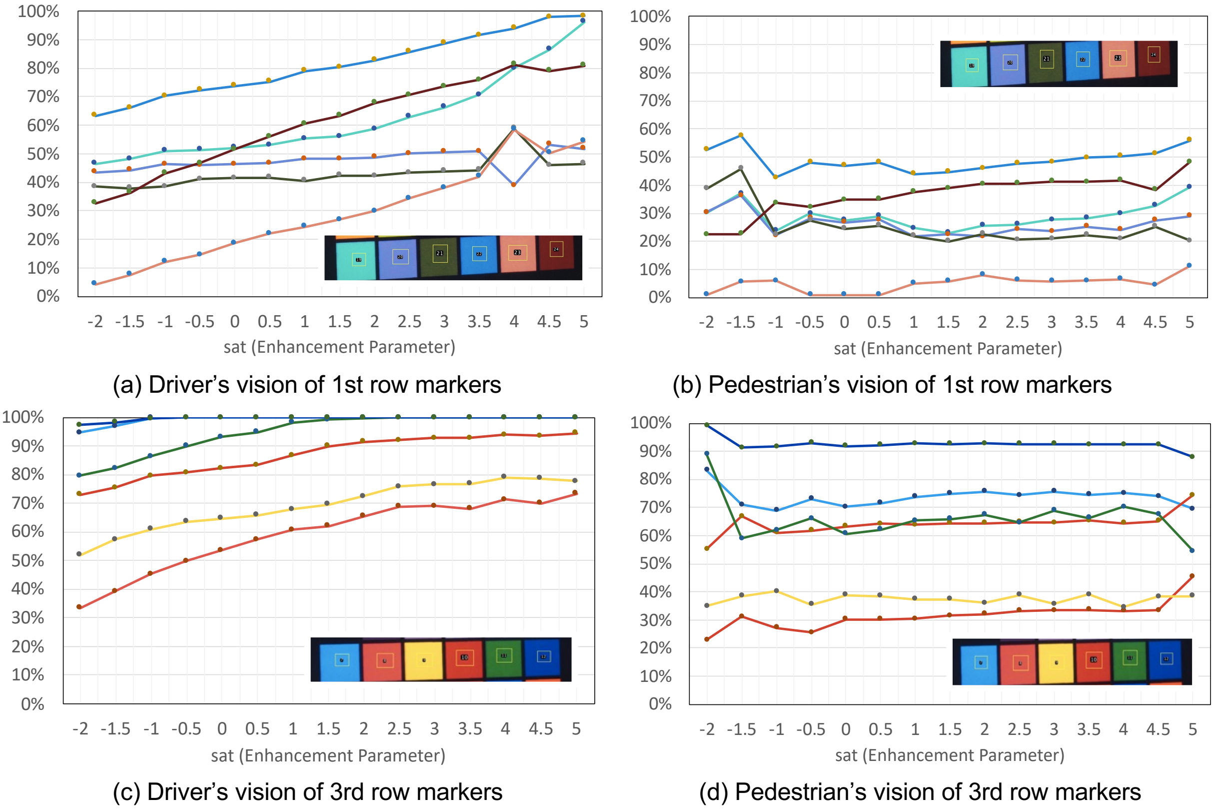
(a) Target scene (b) Captured image **C'**
(c) Reference image **R** (d) Projection images
(e) Driver's vision (f) Pedestrian's vision

Fig. 5 Processing outputs and projection results

In this situation, the driver sees an enhanced roadway scene $I_d \approx \frac{1}{2} K I_p^+$, where K is a roadway reflectance. It is because the temporal optical shutter installed on the windshield passes through the positive pattern projection. In contrast, the system camera exposes both positive I_p^+ and negative I_p^- pattern projection without the optical filter. Therefore, the system obtains $I_d \approx \frac{1}{2} K(I_p^+ + I_p^-)$. It is equivalent to a scene with a static white illumination that is proportional to K. It gives an actual scene appearance.

4 Experimental setup and results

Fig.4 shows our experimental setup. We used Ximea MQ013CG-E2 with a resolution of 1280 × 800 pixels as a system camera and BenQ TH671ST with 1920 x 1080 pixels as a projection headlight unit and, a 3.2GHz 6



(a) Driver's vision of 1st row markers (b) Pedestrian's vision of 1st row markers

(c) Driver's vision of 3rd row markers (d) Pedestrian's vision of 3rd row markers

Fig. 6 Chroma saturation of the color markers in each condition

Core i7 computer (Mac mini 2018) with 32GB memory. The processing speed ranged from 12.9 fps to 17.8 fps depending on the enhancement pattern generation's image processing algorithm.

Fig.5 shows intermediate images and projection results for the target scene (a) that is printed with photo-matte paper and placed on the wall. (b) shows normalized capture image. With the image processing for the scene enhancement, the system generates a reference image (c). We applied a brightness equalization algorithm for the scene enhancement in this sample. (d) shows a positive and a negative projection image. Since the inverse gamma function is applied for these images, the contrast is changing from (c). After the projection with 3D mode, we obtained a driver's vision with 3D shutter glass (e) and a pedestrian's vision without 3D shutter glass (f). From these results, we can confirm that the visible color of the pedestrian vision does not change while the chroma saturation is enhanced for the driver's vision.

To evaluate the potential of illumination pattern imperception for pedestrian vision while driver vision is enhanced, we measured chroma saturation on the color marker without and with the optical shutter as a Driver's vision and a Pedestrian's vision. For this evaluation, we used the ColorChecker chart [7] placed in a dark room as a target, and applied a chroma saturation enhancement

$$\boldsymbol{R} = sat\,(\boldsymbol{C}' - \bar{\boldsymbol{C}}) + \boldsymbol{C}' \qquad (1)$$

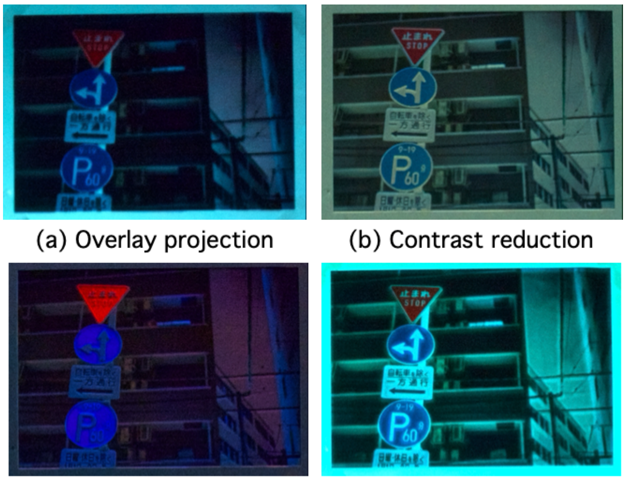
Table 1 Averaged slopes and RSQs

ColorChecker row #		Slope(RSQ)	
		Pedestrian	Driver
#1		0.254 (0.29)	4.707 (0.76)
#2		0.492 (0.29)	4.153 (0.91)
#3		0.253 (0.23)	2.577 (0.72)
#4		-0.727 (0.13)	0.743 (0.51)

for the "image processing" shown in Fig.3. Where $\boldsymbol{C}, \boldsymbol{R} \in \mathbb{R}^3$ are RGB values of a corresponding single pixel, $\bar{\boldsymbol{C}}$ is a grayscale conversion of $\boldsymbol{C}'$, and sat is an enhancement parameter. From Fig.6, we can see a correlated trend between chroma saturation and sat parameter in Driver's vision in contrast to Pedestrian's vision. This trend also can be confirmed from Table 1 that represents the average slopes of the linear function fitting and its square of the correlation (RSQ) at each row. However, since some markers with vivid color reached 100% saturation, row #3 could not get a high Slope average for Driver's vision. Because the markers in row #4 do not have chroma in nature, they could not be confirmed for any trend between measured chroma saturation and the enhancement parameter in both visions.

5 Discussion

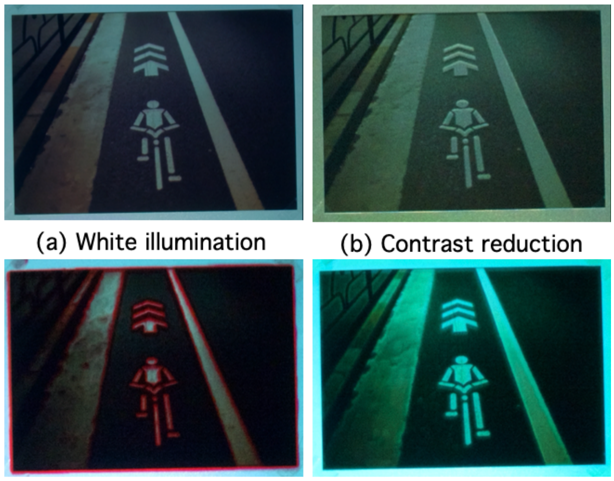
We confirmed illumination with our proposed method does not harm visibility for pedestrians and oncoming car



(a) Overlay projection (b) Contrast reduction

(c) Brightness equalization (d) Edge enhance-W

Fig. 7 Enhancement for road sign



(a) White illumination (b) Contrast reduction

(c) Edge enhance-R (d) Edge enhance-W

Fig. 8 Enhancement for road line and icon

drivers from the experimental results. The remaining issue that needs to be addressed with this lighting technique is what kind of enhancement is effective.

For the road sign shown in Fig.7, the overlay projection (a) projects a captured image on the scene, and it boosts contrast and improves a sense of distance. However, it drops the visibility of the sign plates. In contrast, contrast reduction (b) which is a tone-mapping with a concave-down function reduces the scene brightness deviation. It makes the scene to a flat appearance and improves the visibility of the sign plates. The extreme brightness manipulation is a brightness equalization (c). It attempts to make brightness uniform for the entire scene with the projection. As a result, the dark red road sign is turned to illuminate, and it is attractive. However, such exceeded brightness manipulation makes visibility degrease. The edge enhancement with white flame overlay (d) does not make strong shading while boosting contrast, and it makes road signs attractive. Therefore, it is a better effect for the road sign.

For the road line and icon shown in Fig.8, the contrast reduction (b) drops the relative brightness of the line and icon. However, the line is well recognized from near to far for uniformity compared with a simple white illumination (a). From this perspective, edge enhancement with red flame (c) and white flame (d) overlays cannot improve line visibility, although the icon is enhanced.

It should be noted that the scene brightness is dominant for visibility, so we need to improve the brightness for the driver's vision. However, it has optical restrictions depending on image processing, as shown in this section.

6 Conclusion

In this work, we proposed a concept of the driver's vision support using imperceptive pattern illumination for automotive lighting. For this imperceptive pattern illumination, we used a complementary pattern projection with a 3D projection function. Through the experiment, we confirmed that the visibility of the in-vehicle driver is improved by pattern illumination projection while the pedestrians and on-coming car drivers perceive it as white illumination.

The best enhancement algorithm depends on the situation, but we confirmed that the edge enhancement and contrast reduction benefit the roadway scene enhancement. It should be addressed in our future work.

Acknowledgement

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