

Image Fusion for Night-time Pedestrian Recognition Assistance

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ABSTRACT

Fusion images have been generated by combining near infrared images of road areas and far infrared images in order to reduce vehicle-pedestrian accidents at night. In past studies, fusion images were generated by combining the entire area of near infrared images and far infrared images, which resulted in image information unnecessary for pedestrian recognition being fused, such as street illumination and the headlights of oncoming vehicles. It might be achievable to enhance efficiency in providing visual driving assistance by reducing these influences. The current research applied gradation processing to combine only the road area of near infrared images and far infrared images, and generate partial fusion images that primarily provide pedestrian and road area information. The effectiveness of this type of fusion image in providing visual assistance was compared to that of other image types in a volunteer test. Increased accuracy in identifying the location of pedestrians was shown when the new images were employed.

1. Introduction

Road accident statistics indicate that night-time accidents account for approximately 70% of all pedestrian fatalities every year in Japan, and that the leading cause of these accidents is delay in recognition of pedestrians by vehicle drivers⁽¹⁾. The development of a visual driving assistance system that would help assist drivers to recognize pedestrians at night has been suggested as a means of reducing the incidence of these accidents. Up to the present, research has focused on visual driving assistance systems that detect pedestrians at night and make the driver aware of their presence^{(2), (3)}. The effect of visual driving assistance could be further increased by adding to these functions the presentation of images to make the driver visually aware of the presence of the pedestrian prior to the operation of the detection function.

When a visual driving assistance system displays images to a driver, a process commences in which the driver becomes aware of the presence of a pedestrian and its position by comparing the image with the actual road environment. The road area information such as the shape of the road and the position of the white lines is considered important in assisting drivers to detect the presence of pedestrians and to identify their position at

night from the image. It is therefore helpful to present image information on pedestrians and the road simultaneously. The use of far infrared camera images that map the temperature distribution of the human body is useful in making drivers aware of pedestrians at night⁽²⁾. However, it is challenging to obtain information on the environment including the road surface using a far infrared camera.

In this case, it is necessary to use near infrared cameras suited to imaging of the environment at night⁽⁴⁾. The combination of these two types of images to generate fusion images would enable two types of image information to be presented in the form of one single image. Herrington et al. have proposed a method of image fusion in the frequency domain for the entire road area to create these fusion images⁽⁵⁾.

In order to enhance the effectiveness of visual driving assistance systems in assisting driver's recognition of the presence of pedestrians at night, the current research studied a partial image fusion method that uses only limited information required for recognition of the presence and position of a pedestrian, relative to the conventional method that formed fusion images using information from the entire road environment. The method proposed by Herrington et al. uses the Discrete Haar

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Wavelet Transform to generate a fusion image that shows the entire road environment at night as comparatively bright. However, because the area around the pedestrian is also made brighter, the pedestrian may become correspondingly harder to identify, thereby reducing the accuracy of pedestrian recognition. For this reason, pedestrian recognition at night requires image information to possess contradictory characteristics: The area around the pedestrian should be comparatively dark, while the entire road area should be displayed brightly. Similarly, it is also necessary to reduce light noise such as the headlights of oncoming vehicles that may cause halation in images and consequently make it harder to identify pedestrians. This paper therefore proposes a method of formulating partial fusion images that combine only the road area by applying gradation processing to near infrared images that contain the road area information required for the recognition of pedestrians at night. The results of verification of the effectiveness of this method in providing visual driving assistance will also be discussed.

2. Formulation of Fusion Images using Gradation Processing

2.1. Issues in Conventional Method

Figure 1 shows an example of the generation of a fusion image using the method employed by Herrington et al. This fusion image is generated using the entire road environment (termed an “all area fusion image” below), and in some cases, these images may not provide sufficient visual assistance for pedestrian recognition due to the saturation of the brightness of the image caused by environmental light and light noise. The following two examples can be indicated:

- (1) Environmental light: Areas close to city streetlights [Fig. 2(a)]
- (2) Light noise: The headlights of oncoming vehicles [Fig. 2(b)]

As shown in Fig. 2(a), pedestrian recognition could

be challenging when the light from streetlights is combined with the pedestrian image. As can be seen in Fig. 2(b), when the light from the headlights of oncoming vehicles directly enters a near infrared camera, it may be shown in the fusion image as close to the upper limit for image brightness and cause halation.

With regard to the illumination from streetlights, a method may be considered in which only the road area of the near infrared image is isolated and combined with a far infrared image. However, this would have a minimal effect in reducing halation, because the headlights of oncoming vehicles would also be shown brightly in the image due to reflection from the surface of the road and other factors. In addition, there would be a significant variation in brightness between the areas near the boundary of the road area, which would produce a sense of visual incongruity. For these reasons, this research applied gradation processing to near infrared images in

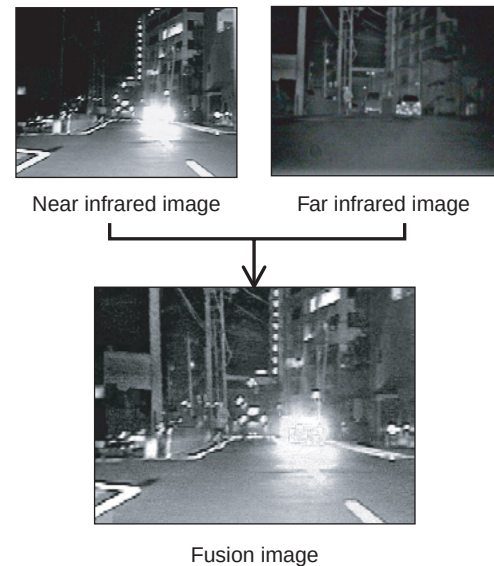


Fig. 1 Fusion image

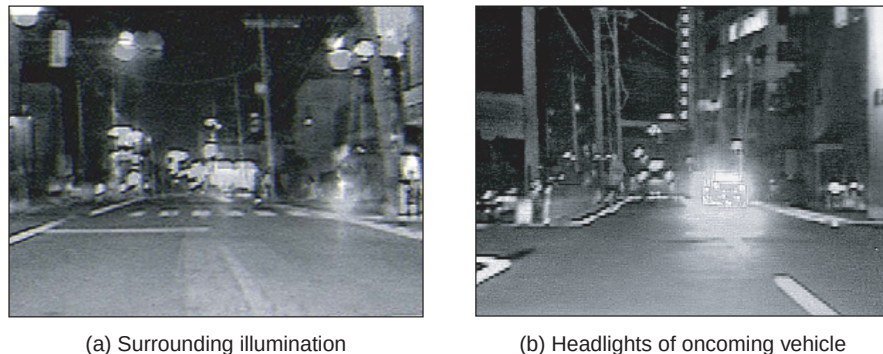


Fig. 2 Examples of halation in all area fusion image

order to create fusion images with reduced halation that combined only the road area.

2.2. Gradation Processing

A gradation processing was established in which the brightness of the areas of a near infrared image other than the area to be fused (the “fusion area”) was attenuated to 0. Figure 3 shows an image of the process. The boundary value y_b is used to determine the fusion area. The brightness value $I(x, y)$ is multiplied by the gradation coefficient $G(y)$ to determine a new brightness value, $I_g(x, y)$ [Eq. (1)]. The gradation coefficient $G(y)$ attenuates brightness in such way that the brightness value of a pixel is closer to 0 for the pixel closer to the boundary of the fusion area, $y = y_b$ and all the pixels beyond the boundary are given the brightness value of 0 [Eq. (2)]. The process of attenuation is more gradual for higher gradation gain. When a fusion image is generated, the use of high gradation gain reduces discrepancies in brightness that occur near the boundary of the fusion area, $y = y_b$. However, the near infrared image becomes darker overall, and the amount of information from the near infrared image incorporated in the fusion image declines. This makes it important to select the level of gradation gain appropriate to the environment. Below, fusion images generated using gradation processing will be termed “gradational fusion images.”

$$I_g(x, y) = I(x, y) \cdot G(y) \quad (1)$$

$I(x, y)$: Brightness value of near infrared image at coordinates (x, y)

$I_g(x, y)$: Brightness value of near infrared image at coordinates (x, y) following gradation processing

$G(y)$: Gradation coefficient

$$\begin{aligned} G(y) &= 1 - 1/\exp(A \cdot (y - y_b)) & (y \leq y_b) \\ G(y) &= 0 & (y > y_b) \end{aligned} \quad (2)$$

y_b : Boundary value of fusion area in y-axis

A : Gradation gain, $(A \geq 0)$

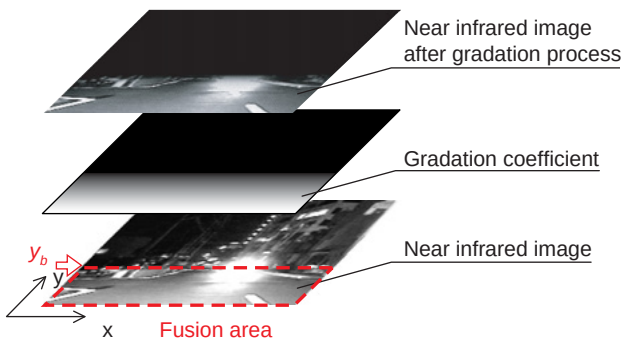


Fig. 3 Gradation process

3. Verification Test for Effectiveness of Gradational Fusion Image

Gradational fusion images were generated using a far infrared camera and a near infrared camera mounted on a real vehicle to verify the effectiveness of the images in visual assistance. Figure 4 shows the system layout used in the test. A far infrared camera was set up at the front of the test vehicle, with a near infrared camera also positioned on the vehicle. An image processing unit generated fusion images from the images obtained by these cameras, which were then presented to the driver on a head-up display (HUD). The size of the images from both the far infrared and near infrared cameras was 640 x 480 pixels. The procedure employed to generate the gradational fusion image is shown in Fig. 5. Following application of gradation processing to the near infrared images, the images were fused in the frequency domain using the Discrete Haar Wavelet Transform.

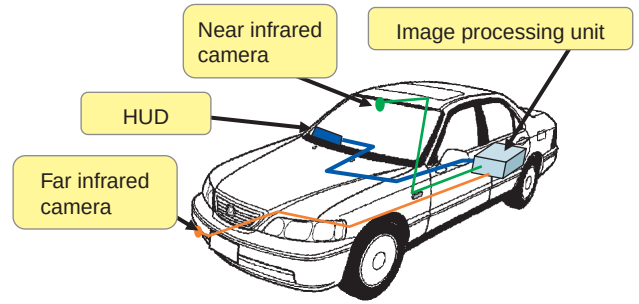


Fig. 4 System layout

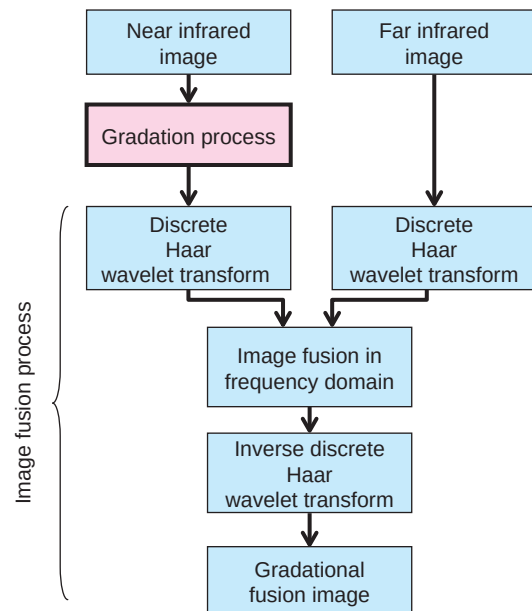


Fig. 5 Flow of construction of gradational fusion image

3.1. Effectiveness of Gradational Fusion Image

Figures 6(a) and 6(b) show a comparison of fusion images with and without gradation processing. In Fig. 6(a), gradation gain was set at 0, resulting in the generation of a partial fusion image using only the road area, without gradation processing. By contrast, Fig. 6(b) shows a gradational fusion image generated using a gradation gain of 0.05. In both cases, the boundary value of the fusion area (y_b) was set at 180. As the graph in Fig. 7 indicates, in the gradational fusion image shown in Fig. 6(b), the gradation coefficient becomes progressively smaller as the y -coordinate of the pixel approaches y_b ($80 < y < 180$), and reaches 0 when it becomes greater than y_b . By contrast, in the partial fusion image shown in Fig. 6(a), the gradation coefficient does not change progressively, simply changing from 1 to 0 when the fusion image boundary, y_b , is crossed.

As discussed above, the verification of the effectiveness of the images in assisting the driver to recognize the position of the pedestrian focused on the road information and brightness around the pedestrian. In both the partial fusion image with only the road area combined [Fig. 6(a)] and the gradational fusion image [Fig. 6(b)], road information, such as the white lines, is shown together with the image of the pedestrian. In addition, the area around the pedestrian is shown as comparatively dark in both images. This indicates that the effectiveness of the two images is identical in terms of

assisting pedestrian position identification, whether or not gradation is employed.

With regard to the headlights of oncoming vehicles, in the partial fusion image (Fig. 6(a)), the lights in the road area are shown as bright, without reduction of halation. In the gradational fusion image (Fig. 6(b)), however, the brightness of the lights in the road area has been attenuated, and halation has therefore been reduced. This indicates that gradation processing is effective in reducing halation.

3.2. Comparison with Images Generated Using Conventional Methods

Figure 9 compares a far infrared image, a near infrared image, an all area fusion image, and a gradational fusion image. All images were created for the road scene described in Fig. 8. The far infrared image [Fig. 9(a)] allows recognition of the presence of the pedestrian, while the position of the pedestrian is challenging to identify due to the lack of road information such as the white lines. Although the near infrared image [Fig. 9(b)] contains relatively plenty of road information, the headlights of the oncoming vehicle and the surrounding illumination such as streetlights could cause halation, making it challenging to identify the presence of the pedestrian. The all area fusion image [Fig. 9(c)] that fused the entire area of these images allows recognition of the presence and position of the pedestrian. However, the effect of the environmental



Fig. 6 Comparison of partial fusion image and gradational fusion image

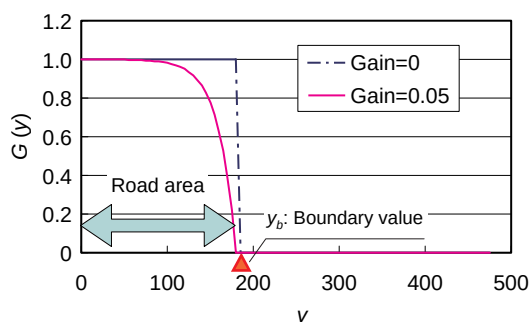


Fig. 7 Gradation coefficient $G(y)$

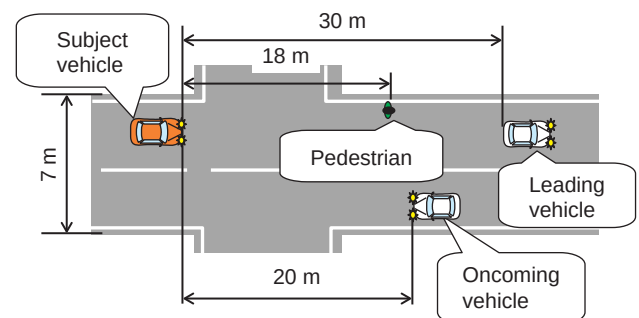


Fig. 8 Road scene

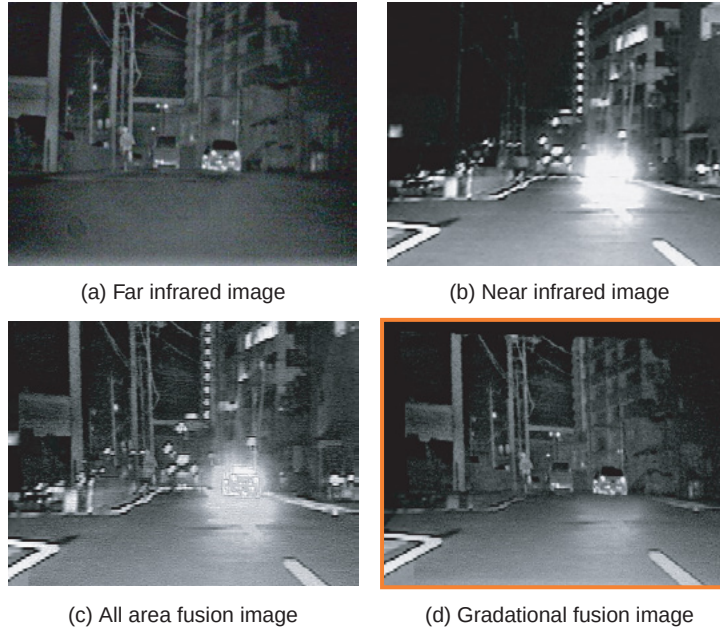


Fig. 9 Comparison of images

light and light noise is still an issue with this image. Compared to these three images, the gradational fusion image [Fig. 9(d)] is with reduced halation due to the surrounding illumination and the headlights of the oncoming vehicle. Given these results, it is anticipated that the gradational fusion images are more effective in providing visual assistance for the recognition of pedestrians than the other image types.

4. Verification Tests for Effectiveness of Visual Assistance with Test Subjects

Tests were conducted with test subjects in order to verify the effectiveness of the gradational fusion images in providing visual assistance for accurately identifying the position of pedestrians.

4.1. Test Method

4.1.1. Test device

It was desirable to verify the effectiveness of the gradational fusion images in providing visual assistance under conditions close to those encountered in actual driving environment. The simulator shown in Fig. 10, a mock-up of the driver's seat of a real vehicle, was constructed based on this requirement. A HUD positioned above the instrument panel in front of the driver was used to display images for visual driving assistance. A screen was set up in front of the driver's seat, and the images of driving environments shot using an ordinary video camera were displayed in order to simulate actual driving conditions.

4.1.2. Test procedure

The effectiveness in providing visual driving assistance was compared by showing either of the far infrared images or gradational fusion images on the HUD shown in Fig. 10 (a), and measuring the time to detect the pedestrian position. Ten different images covering different scenes were prepared. From among these images, the simulator randomly selected the one to be displayed. Alarms were used to notify the test subjects that images would be displayed. The amount of time spent looking at an HUD changes with the actual driving load, becoming shorter as the driving load increases. The following image

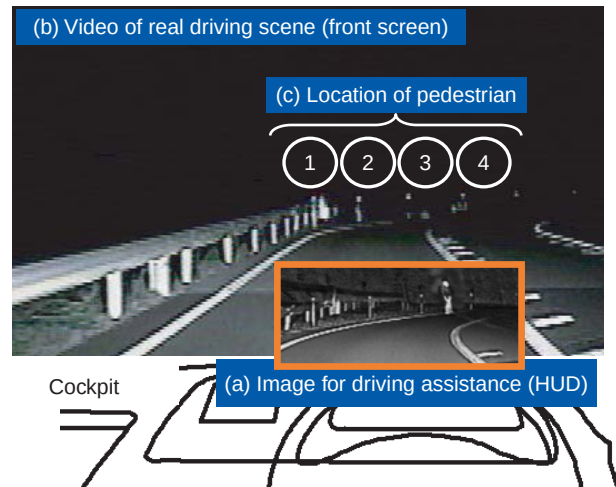


Fig. 10 Outline of experimental set-up

display times were employed in order to reproduce this situation:

High driving load: 0.3 sec

Medium driving load: 0.5 sec

Low driving load: 1.0 sec

To quantify the effectiveness of the two types of images in providing visual driving assistance, the road scene displayed on the screen shown in Fig. 10 (b) were divided into four areas [Fig. 10 (c)]. Each test subject was asked to identify the area in which the pedestrian was located for each image display time, and the percentage of correct answers was calculated.

4.2. Test Results

Test subjects consisted of six men and one woman ranging in age from their 20s to 40s. Figure 11 shows

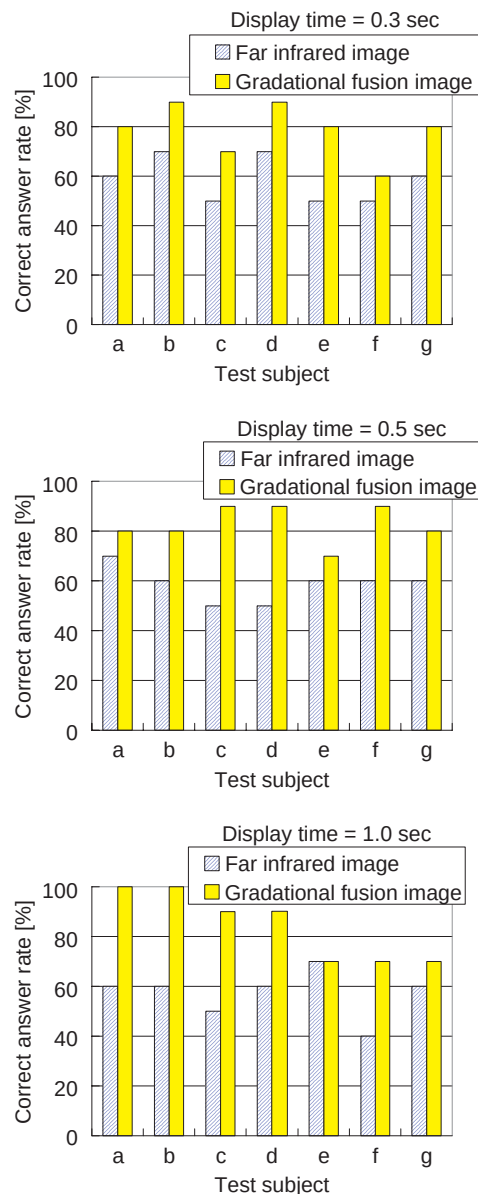


Fig. 11 Location recognition rate of pedestrian

the percentage of correct answers for each test subject and image display time. All test subjects, with the exception of one (subject e at a display time of 1.0 sec), produced a higher percentage of correct answers for gradational fusion images than for far infrared images. Figure 12 shows a comparison of the percentage of correct answers for gradational fusion images and far infrared images for each display time. The percentage is approximately 1.4 times higher for gradational fusion images for all display times. This indicates that gradational fusion images are more effective than far infrared images in assisting recognition of pedestrian position, regardless of the driving load.

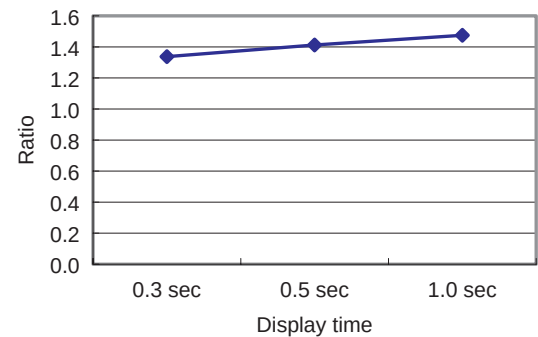


Fig. 12 Correct answer rate for gradational fusion images normalized by that for far infrared images

5. Conclusion

A method of generating fusion images limited to the road area through the application of gradation processing to near infrared images containing road area information has been developed in order to help provide visual assistance to drivers in recognizing pedestrians at night. The halation in images caused by the surrounding illumination and the headlights of oncoming vehicle was a factor in determining that the conventional image fusion method was less adequate in helping provide visual driving assistance. Gradational fusion images were generated using the road area from near infrared images in order to respond to this factor, and were shown to be more effective in assisting recognition of pedestrians. In addition, the halation caused by the headlights of oncoming vehicles was reduced. Simulator tests with test subjects of the effectiveness of the gradational fusion images in helping provide visual assistance to drivers for the recognition of pedestrians showed that the images increased the accuracy with which the location of pedestrians was identified. These results indicate that the use of this method in a visual driving assistance system can potentially reduce the incidence of pedestrian accidents at night.

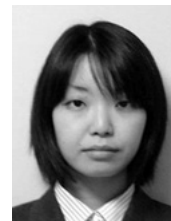
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