Research Report

Image Processing Technology for Rear View Camera (2) : Visibility Improvement by Compressing the Brightness Range of Images

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Abstract

An outdoor scene, where a driver looks through a blind spot monitor, for instance a rear view monitor, occasionally has a very wide brightness range. However, the dynamic range of a liquid crystal display, which is commonly used as an in-vehicle display, is considerably narrow in comparison with the dynamic range of the outdoor scene and the camera to capture the image. Therefore, the darker regions in the image would be under the noise level of the display, otherwise the brighter regions in the image would saturate. To solve the problem, we propose a method to compress the overall brightness range of the image keeping the contrast of objects using image processing. This method suppresses the lower spatial frequency component of the captured image according to the brightness of each pixel. As a result, the image of the outdoor scene can be displayed on an in-vehicle display with high visibility and no side effects, even if the scene has very wide dynamic range.

1. Introduction

Recently, CCD cameras have been installed in many vehicles. One important use of such on-board cameras is recognition of vehicle environments, ex. lane marker detection[1] and obstacle detection. Another important use is visual assistance for a driver such as blind spot monitors, ex. a rear view monitor[2, 3] and blind corner monitor. For the purpose of visual assistance, images have to be displayed with high visibility. However, there are a lot of factors that deteriorate the visibility of in-vehicle displays, ex. low contrast, distortion and the amount of information.

As the first step to improve the visibility of in-vehicle display, we focus on contrast. An outdoor scene where a driver looks through a blind monitor system occasionally has a very wide dynamic brightness range. Therefore, the dynamic range of the image will be very wide. On the other hand, the dynamic range of the liquid crystal displays that are commonly used for in-vehicle displays is considerably narrower than the dynamic range of the outdoor scene and on-board camera. As a result, darker regions of the image would be under the black level of the display, otherwise brighter regions of the image might saturate. To solve this problem, gray-scale modification could be used. However, if part of the gray-scale range is expanded, then the remaining part will contract and the contrast of that range will decrease. In addition, contour emphasis with a spatial filter could be used to compensate for the decrease in contrast. However, the contrast would not be improved enough.

In this paper, we propose a method for displaying an image of an outdoor scene in the dynamic range of current in-vehicle displays. The method maintains the contrast of objects in the image using image processing technology. To fit an image having a wider dynamic range into the range of the display, the method compresses the overall brightness dynamic range by suppressing the illumination component included in the captured image. Video images of various outdoor scenes captured with a rear view camera were evaluated by a subjective method. As a result, the effectiveness of this method has been confirmed.

The outline of this paper is as follows. **Section 2** focuses on the lack of dynamic range of in-vehicle displays. We briefly review a conventional method and propose a new method for compressing the dynamic range of an image in **Section 3**. **Section 4** presents the subjective evaluation to confirm the effectiveness of the method. Finally, we conclude in **Section 5**.

2. Dynamic range of outdoor scenes and in-vehicle displays

In this section, we highlight the problem of visibility of in-vehicle displays due to the lack of dynamic range.

Figure 1 shows a measurement result of the dynamic range of an outdoor scene in fine weather. In this figure, each marker shows the measured brightness of an object in the scene. From this
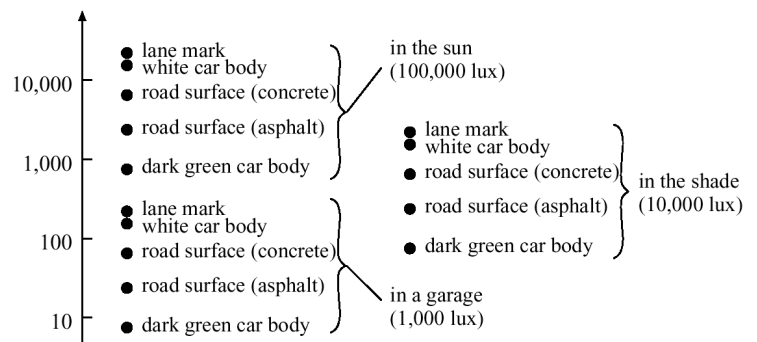
Fig. 1 Dynamic range of an outdoor scene.
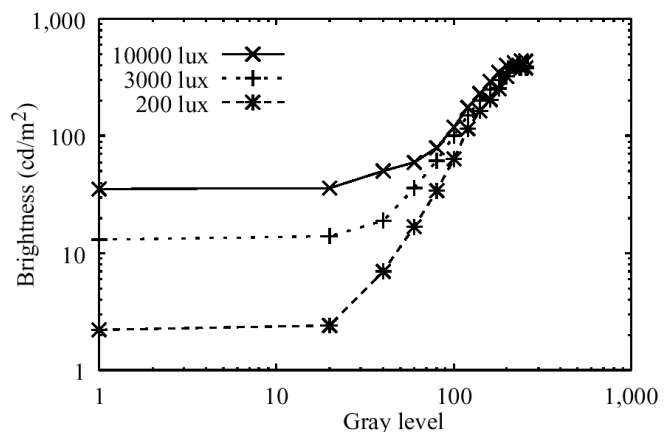
Fig. 2 Dynamic range of a liquid crystal display under several values of illuminance.

figure, a scene with strong shadow and sunlight will have a dynamic range of several thousands cd/m^2. **Figure 2** shows measurement results of the dynamic range of a liquid crystal display under several illuminance conditions. From Fig. 2, the higher the illuminance on the display surface, the narrower the dynamic range of the display. Experimentally, the dynamic range of the display is around 160 under 200 lux and 28 under 3000 lux. Note that the dynamic range of a camera is about 500 for a conventional CCD camera and more than 1000 for a wide dynamic range camera. In any case, the dynamic range of an in-vehicle display is narrower than the dynamic range of the scene and the camera. Consequently, captured images that have wide dynamic range cannot be displayed within the dynamic range of the display. As a result, the darker regions in the image will be in the black level of the display to avoid the brighter regions from saturating.

3. A method of compressing the brightness range of images

In this paper, we propose an image processing method to improve the contrast of the in-vehicle display. The method is based on the idea of the homomorphic filter[4]. We briefly review conventional the homomorphic filter, and then describe our proposed method.

3. 1 The conventional method

The homomorphic filter[4] compresses the overall dynamic range of the original image by suppressing the low spatial frequency components. Brightness $I(x, y)$ at a pixel (x, y) in a captured image is represented as follows:

$$I(x, y) = R(x, y) \times L(x, y) \cdots\cdots\cdots\cdots\cdots\cdots (1)$$

where $R(x, y)$ is the reflectance component of objects and $L(x, y)$ is the illumination component of the environment corresponding to each pixel, as illustrated in **Fig. 3**.

From Fig. 3, information of the illumination
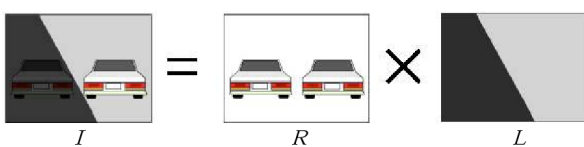
Fig. 3 Brightness I of a captured image.

component is not so important as that of the reflectance component. Therefore, by suppressing the illumination component L, the overall dynamic range of the original image can be compressed while maintaining the contrast of the objects.

Taking the logarithm of (1) gives:

$$\log I(x, y) = \log R(x, y) + \log L(x, y) \cdots\cdots\cdots (2)$$

From Eq. (2), the brightness of the image is represented by the sum of the reflectance component and the illumination component in the domain of logarithmic gray-scale. In general, illumination L is composed of lower spatial frequency components compared to reflectance R. Therefore, the illumination component L can be suppressed by a linear operation having a high pass filter in the domain of logarithmic scale.

3. 2 The proposed method

The conventional homomorphic filter works well when the spatial variance of the illumination component is smooth and not very strong. As was mentioned in **Section 2**, for a blind spot monitor, it is necessary to deal with an image that has a widely varying illumination component, such as a scene in which there are objects both inside and outside of a garage. To reduce such an illumination component, it is necessary to increase the amount of dynamic range compression to improve contrast. However, the increase in the amount of dynamic range compression causes some problems ex. noise amplification and overshoot/undershoot arises at edges due to the relative enhancement of the high spatial frequency component. Noise amplification occurs in darker regions because the S/N ratio of a captured image is low in darker regions and overshoot/undershoot is conspicuous in brighter regions. Our proposed method solves these problems by reducing the amount of suppression of the lower spatial frequency component in both darker and brighter regions. The outline of the block diagram of the proposed method is represented in **Fig. 4**. In this method, lower spatial frequency components are suppressed according to the brightness of each pixel.

The brightness of output image $I_3(x, y)$ can be obtained from:

$$I_3(x, y) = C_1 I_1(x, y) + C_2 I_2(x, y) \cdots\cdots\cdots\cdots (3)$$

where $I_1(x, y)$ is logarithm of the brightness of

original image $I(x, y)$, $I_2(x, y)$ is the low spatial frequency component of $I_1(x, y)$, and C_1 and C_2 are weighting coefficients for $I_1(x, y)$, $I_2(x, y)$ respectively.

To suppress the illumination component without causing any side effects ex. noise amplification and overshoot/undershoot, weighting coefficients C_1, C_2 were defined as shown in **Fig. 5**. The amount of suppression of the lower spatial frequency
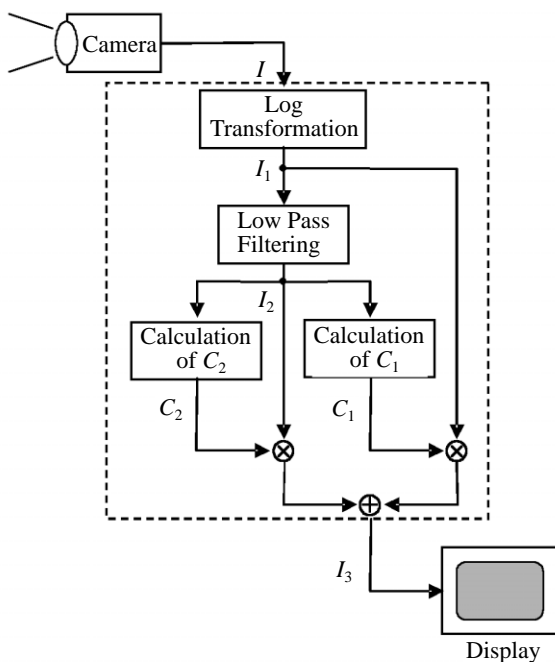
Fig. 4   Block diagram outlining the proposed method.
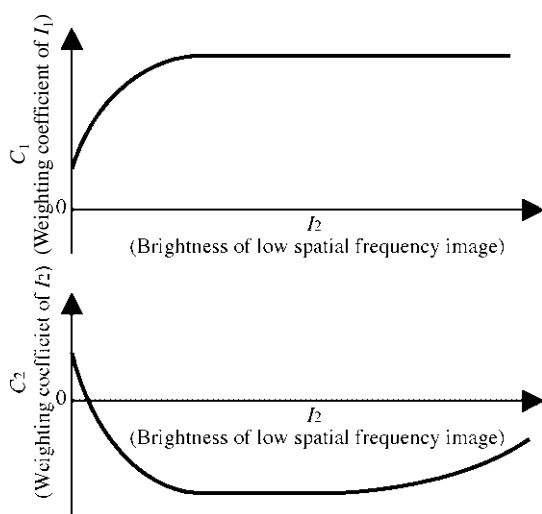
**Fig. 5**   Characteristic of C_1, C_2.

component is uniform in the middle brightness range, decreases according to the decrease in $I_2(x, y)$ in the darker range, and decreases according to the increase of $I_2(x, y)$ in the brighter range.

Due to the simple form of Eq. (3), the part within the broken rectangular line in Fig. 4 can be readily implemented in hardware. **Figure 6** shows a photograph of the prototype. It decodes input NTSC video signals into field images (640×240 pixel) and outputs the processed images as NTSC video signals.

An example of the processed image is shown in **Fig. 7**. In this case, the overall range of the brightness is compressed down to about 1/3 of that of the original image. Figure 7 indicates that our method can display a wide dynamic range image on an in-vehicle display within a limited dynamic range without loosing the contrast of objects.

4. Subjective evaluations

To confirm the effectiveness of this method, images processed with this method have been evaluated by paired comparison with original images for a variety of scenes captured with a rear view camera. Evaluations were carried out in a room under two conditions of illuminance on the display. An illuminance of 8000 lux (lit by halogen lamp) corresponds to around maximum illuminance on an instrumental panel display lit by sunshine indirectly and the illuminance of 300 lux (lit by room light) corresponds to average illuminance on an instrumental panel display in cloudy or rainy weather. **Table 1** shows the types of evaluated scenes and number of scenes evaluated by each
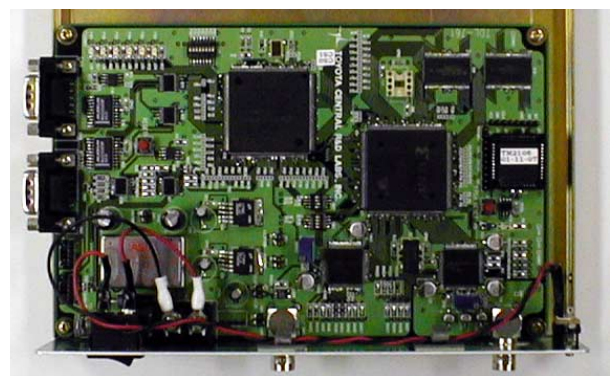
Fig. 6   The prototype.

observer under each illuminance condition.

The two identical 7-inch liquid crystal displays were placed side by side at a distance of 80 cm from an observer. A pair of original and processed video images was displayed simultaneously. The observer chooses the better image of each pair after watching for three seconds, based on image realism and object visibility criteria. The observers were 20 men and 20 women, whose ages ranged from 20 to 65.

Figure 8 shows the ratio of the processing images to the original images, as selected by the observers. Figures 8(a), (b) and (c) correspond to the type of scene under two illuminance conditions in Table 1. In category (a), the visibility of the original images was worst, because the dynamic range of the scene was wide and the dynamic range of the display was narrow. In category (c), the visibility of the original images was good, so there was no need to improve the visibility. In Fig. 8, for the criterion of object visibility, the images processed with the method

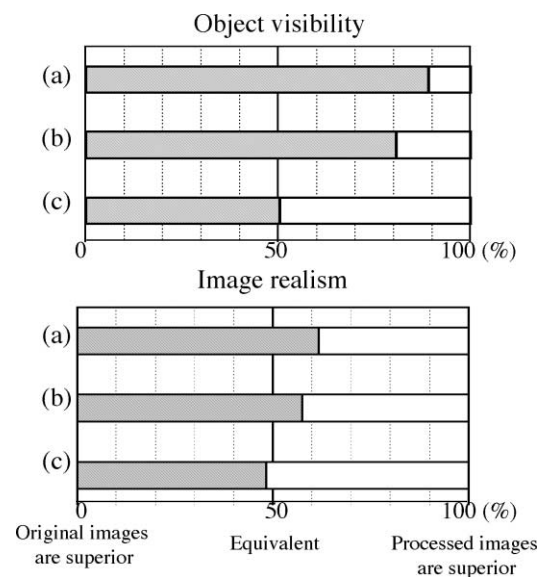were superior to the original images in category (a) and (b), and the processed images and the original images were equivalent in category (c). As a criterion for image realism, the difference between processed images and original images was not so remarkable, but the processed images were a little better. By comparing (a), (b) and (c), the worse the

Table 1 Number of scenes evaluated by each observer.

		Illuminance on the display	
		8000 lux	300 lux
Type of Scene	In fine weather, daytime (strong shadow)	(a) 4	(b) 4
	In fine weather, daytime (normal shadow)	2	2
	In fine weather, evening	-	(c) 2
	In cloudy weather, daytime	-	2
	In rainy weather, daytime	-	2

(a) Original image

(b) Processed image

Fig. 7　Example of the image obtained using the proposed method.

(a) The scenes in fine weather at daytime.
(Illuminance on display is 8000 lux.)
(b) The scenes in fine weather at daytime.
(Illuminance on display is 300 lux.)
(c) The scenes in cloudy or rainy weather at daytime and fine weather at evening.
(Illuminance on display is 300 lux.)

Fig. 8　Results of the evaluation of the proposed method by paired comparison between original and processed images.

visibility of the original image, the more effective the proposed method. From the above discussion, the effectiveness of the proposed method has been confirmed.

5. Conclusions

Outdoor scenes occasionally have very wide brightness dynamic ranges. To show an image of such a scene to a driver, an in-vehicle display needs a dynamic range of several hundred. However, the substantial dynamic range of an in-vehicle display is considerably narrower than this. In our proposed method, overall brightness dynamic range has been compressed without side effects. The proposed method is easy to implement in hardware for real time processing. Therefore, the image of an outdoor scene can be displayed on current in-vehicle displays with high contrast, even if the images have wide dynamic ranges.

The method was evaluated by paired comparison of video images of various scenes captured with a rear view monitor camera. From these results, the effectiveness of this method has been confirmed.

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