Proceedings of the
2007 IEEE Intelligent Vehicles Symposium
Istanbul, Turkey, June 13-15, 2007

Visibility Estimation under Night-time Conditions using a Multiband Camera

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Abstract— **Various driver-assistance systems are currently being developed that make use of on-vehicle cameras. However, the imaging conditions and the methods used to detect objects are different for each system. Therefore, a special camera is often needed in order to satisfy the requirements of each system. A camera that can be shared by multiple systems will become essential when more systems are put to practical use in the future. Therefore, a multiband camera has been developed that can provide both color images and near-infrared images. The camera includes a special filter that improves on the Bayer filter arrays that are used in single-chip digital color cameras, and it can simultaneously obtain images covering four wavelength bands that have the same optical axes and fields of view. Moreover, a method for estimating the driver's visibility when using the camera is described in this paper.**

I. Introduction

Many driver assistance systems have been developed recently that are designed to increase safety and comfort in vehicles [1]-[4]. Sensing technologies incorporating radar and cameras are essential components of these systems, in order to recognize the lane that the vehicle is traveling in and to detect obstacles [5]-[7]. Cameras in particular have been effectively utilized in many systems because they can provide the driver with images that cover blind areas around the vehicle and they can be used to detect specific objects by making use of image-processing techniques.

However, the imaging conditions and the detection of objects by cameras can be very variable according to the purpose for which the system is used. Therefore, it is very difficult to unify the specifications for such a camera, including imaging wavelength band, field of view and resolution. Consequently, special cameras have often been required for each system. For example, color cameras are utilized for rear-view monitoring systems and for blind-corner monitoring systems that provide images of blind-spots that the driver cannot see directly. Stereo-vision techniques have been introduced for collision-avoidance assistance systems in order to detect vehicles and pedestrians in the forward direction [8], [12]-[13]. Moreover, infrared technology is now used in night-vision systems that allow the driver to see further than is possible with the current range of headlights.

It is expected that even more systems will be developed in the future. Cameras with high specification and low cost are required for shared use in plural systems because space for installing cameras in a vehicle is often limited.

In addition, some on-vehicle cameras have to work not only in the daytime but also during the night. In particular, the lighting equipment is important when the cameras are required to work in night-time conditions. However, visible lighting equipment cannot be used to illuminate inside the vehicle or in an extended region in front of the vehicle because it would dazzle pedestrians and other drivers. Therefore, it would be more effective to utilize infrared technology. From now on, the use of infrared rays, which are invisible to the human eye, will be expanded in automotive applications. Hence, it is important to be able to use visible light and infrared rays simultaneously [9].

Therefore, a multiband camera has been developed that can simultaneously obtain both color images and near-infrared images for the purpose of integrating imaging wavelengths. The camera can obtain four different images, consisting of three visible wavelength bands (RGB) and the near-infrared band (I). Therefore, it can provide various images, such as a color image, an infrared image and a visible monochrome image, depending to the requirements of the system. Moreover, all four images that are obtained by the camera have the same field of view and their optical axes are also the same. Consequently, image processing using both a color image and the infrared image is easily achieved.

In addition, a method for estimating a driver's visibility under night-time conditions when using such a multiband camera is introduced in this paper. This can be achieved by a simple image processing operation, which calculates the differences between a visible monochrome image and an infrared image. By applying this technique to a night vision system, the system can select only those pedestrians and obstacles that the driver cannot see because of the darkness when using conventional headlights.

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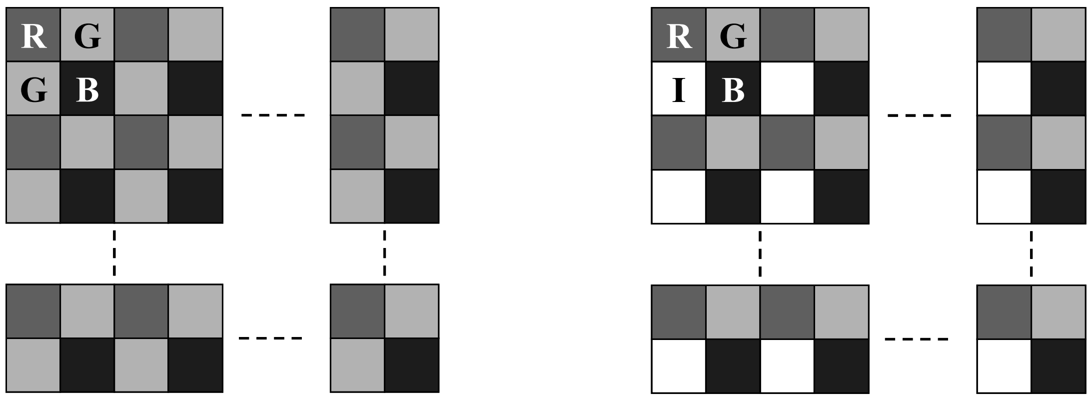
II. MULTIBAND CAMERA

The appearance of the multiband camera is shown in Fig. 1. The camera includes a special filter in order to obtain light from four wavelength bands simultaneously. Fig. 2 shows the structure of the filter.

Fig. 2 (a) shows a color filter array called a "Bayer mask", which is generally used in most of the single-chip digital image sensors that are used in digital cameras and camcorders. R, G and B in Fig. 2 (a) represent the red, green and blue filters, respectively, and each element of the filter corresponds to one pixel of the image sensor. Although the color resolution is lower than the luminance resolution, a full-color image can be obtained by applying appropriate de-mosaicing algorithms [14]-[16], which can be used to interpolate a complete set of red, green, and blue values for each point. Since color information can be obtained by the

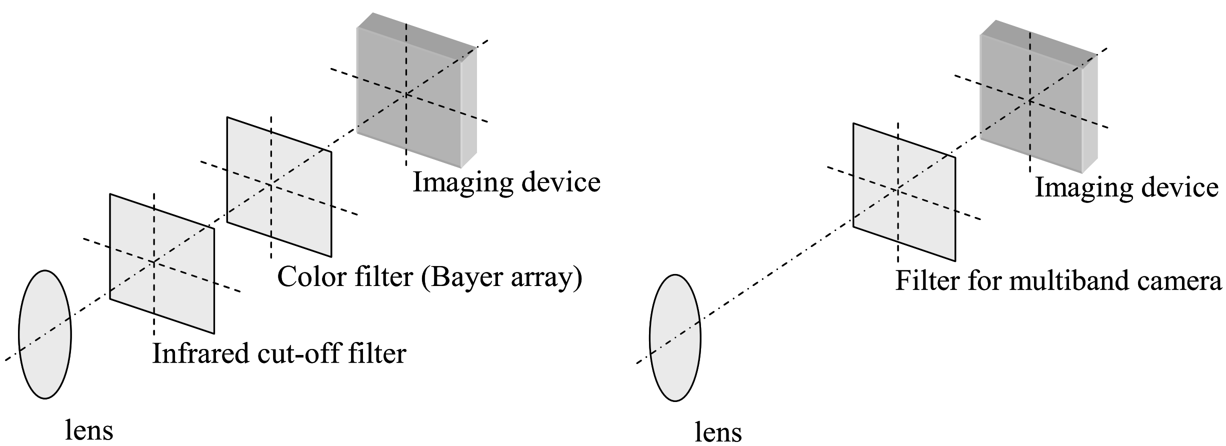
Fig. 1. Appearance of the multiband camera



(a) Bayer array

(b) Array for multiband camera

Fig. 2. Structure of color filter array



(a) Single-chip digital color camera

(b) Multiband camera

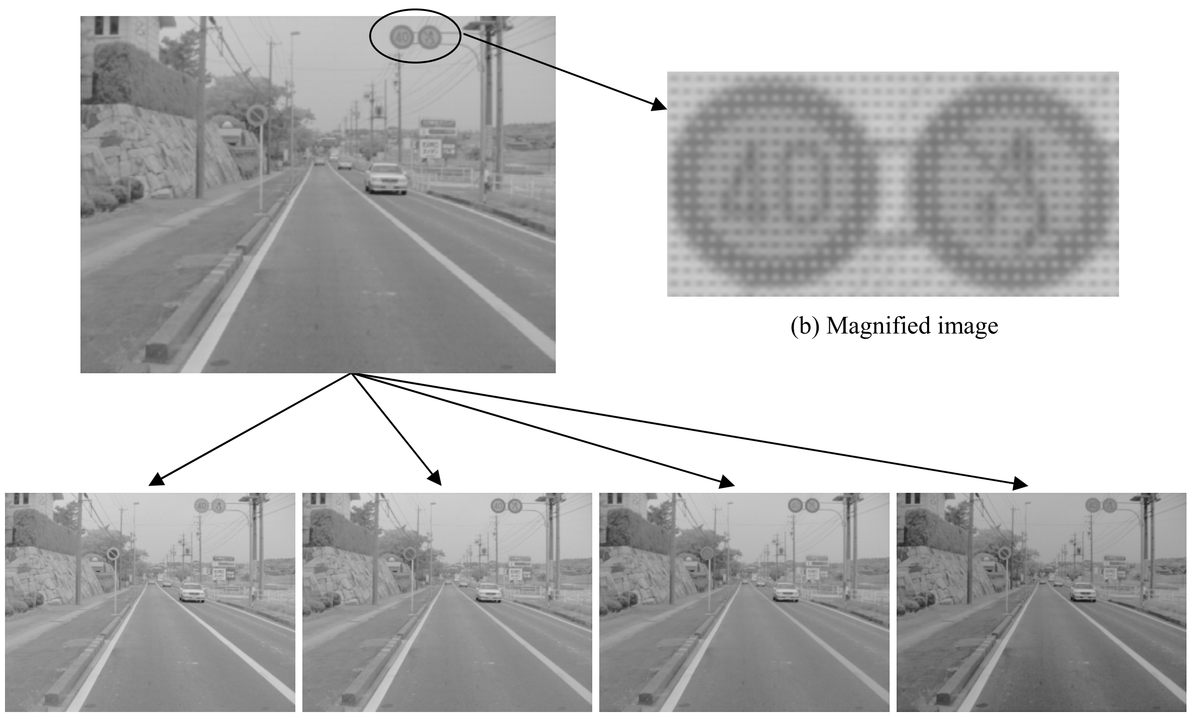
Fig. 3. Structure of a single-chip digital camera and of a multiband camera.

use of a simple structure without prisms or mirrors due to the filter, miniaturized color cameras can be achieved with low cost.

On the other hand, Fig. 2 (b) shows the filter array that was used in the multiband camera that we developed. A visible light cut-off filter (I) is substituted for either of the two green filters in the Bayer array. The camera can obtain information in the near-infrared spectrum by altering the structure of the optical filter because the imaging device has the sensitivity in the near-infrared region.

The structure of the single-chip digital camera and the multiband camera is compared in Fig. 3. Because the RGB filters transmit near-infrared rays, an infrared cut-off filter is placed in front of the Bayer filter to improve color reproduction in a conventional single-chip color camera. However, such a filter cannot be used in a multiband camera, which has to obtain near-infrared rays. Therefore, the pixels that are assigned to the RGB filters are corrected using the

(a) RAW Image



(b) Magnified image

(c) Red-band image (d) Green-band image (e) Blue-band image (f) Infrared-band image

Fig. 4. A sample of the images obtained from a multiband camera

TABLE 1. Specifications of the multiband camera

Feature	Specification
Resolution	642(H) x 482(V) pixel
Frame Rate	60 fps (maximum)
Scan Mode	Progressive
Dynamic Range	>= 120 dB
Spectral Range	400 – 1100 nm
Size	45mm × 30mm × 35mm

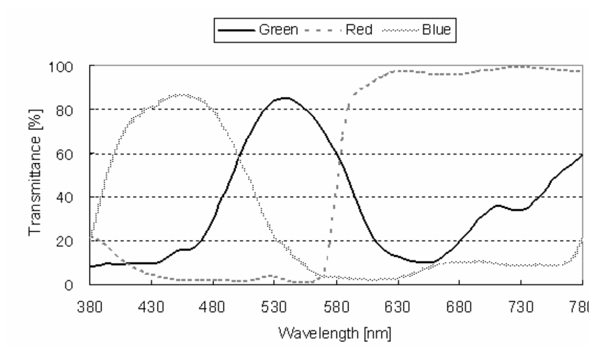


Fig. 5. Characteristics of RGB filters

following equations in order to improve color reproduction.

$$v'(R) = v(R) - Kr \cdot v(I)$$
$$v'(G) = v(G) - Kg \cdot v(I) \qquad (1)$$
$$v'(B) = v(B) - Kb \cdot v(I)$$

where *v(R)*, *v(G)*, *v(B)* and *v(I)* indicate the pixel-values assigned to the red, green, blue and infrared filters, respectively, while *Kr*, *Kg* and *Kb* are coefficients that are defined by the amount of near-infrared rays that are transmitted by the RGB filters. These coefficients are determined on the basis of the characteristics of RGB filters and on some experimental results.

The filter array shown in Fig. 2 (b) means that the camera is capable of providing different systems with different images, such as color images and infrared images. And the camera is more suitable for automotive applications than a system that captures images while switching filters, since it can acquire four images in the RGBI bands without any time-difference issues. Of course, a system that is a simple arrangement of a color camera and an infrared camera could be also built, but in that case, the positions of the objects in the two images would be slightly different because of the differences in the optical axes of the two cameras. Therefore, it would be necessary to determine the correspondence between all of the objects in the two images by image processing, whereas the multiband camera has no need for such a tedious process.

The specifications of the multiband camera are shown at Table 1. The camera has VGA resolution originally, but the resolution of each color is actually QVGA standard, since four pixels form one unit in the special filter array, as shown in Fig. 2. The camera cannot reproduce a full-color image by utilizing de-mosaicing algorithms as conventional single-chip digital cameras can. The imaging device with higher resolution is necessary for improving each color resolution.

Fig. 4 shows a raw image data obtained by the multiband camera and four images of the RGBI bands extracted from the mosaic image. The transmission characteristics of the RGB filters are shown in Fig. 5. If the optical filter is composed of the RGB filters that do not transmit the near-infrared rays, the camera can reproduce the color images without the correction processing shown by the equations (1).

III. Visibility Estimation

A method for estimating the driver's visibility in night-time conditions by considering both a visible image and an infrared image that can be obtained simultaneously using the multiband camera is described in this section.

A. System Structure

Night vision systems have been developed to allow a driver to see further than the range of current headlights in the dark. These systems can be broadly divided into two categories, depending on the methods that are used to obtain the images. One type of system irradiates the surroundings with near-infrared rays that are invisible to the human eye and then captures images by using a near-infrared camera [10]. The other system acquires thermal radiation from the objects that are being detected, such as pedestrians, animals and other vehicles, by using a far-infrared camera [11].

A night vision system with the former structure is utilized here. Fig. 6 shows the lighting conditions under which the system works. The vehicle is mounted with infrared lights along with conventional headlights. The infrared lights emit near-infrared radiation further than the range of the conventional headlights, and an infrared camera is used to capture long-range images that the driver cannot see directly.

By using the multiband camera, the system can recognize the difference between the range of the conventional headlights and the range of the infrared lights. As a result, it can estimate the driver's visibility under night-time

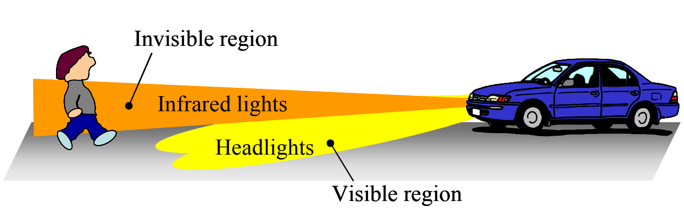


Fig. 6. Lighting condition in night vision system

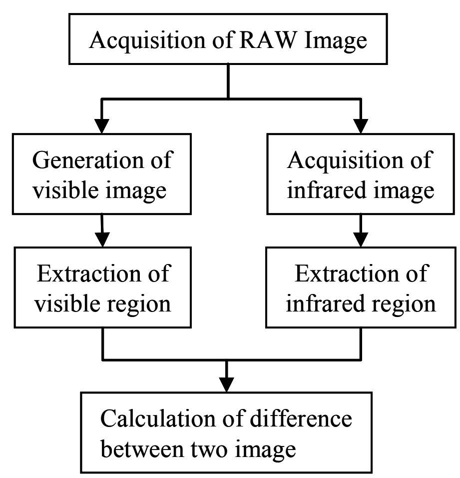


Fig. 7. Flowchat of visibility estimation

conditions.

B. *Procedure for Visibility Estimation*

The method that is used to estimate the driver's visibility is explained in this section. The procedure for visibility estimation is shown in Fig. 7.

A visible image is generated from a color image obtained by the multiband camera. The visible image consists of a monochrome image whose pixel value is the brightness calculated by converting the RGB values into appropriate color space. Only the region irradiated by the headlights is in the visible image. Therefore, the visible region that the driver can see can be estimated by extracting pixels with high brightness from the visible image.

In addition, the region that is illuminated by near-infrared rays can be recognized by extracting those pixels with high brightness from an infrared image that is also obtained by the multiband camera. Consequently, the difference between the two images represents the region that is only illuminated by the near-infrared rays. It is exactly this "invisible" region in which it is difficult for a driver to see.

According to the above procedure, the driver's visibility can be easily estimated by a simple image-processing technique because the images of the RGBI bands have no time differences and a common optical axis.

C. *Experimental Results*

To confirm the effectiveness of the proposed method, some experiments have been carried out and evaluated in a dark road without any streetlights under night-time conditions. A multiband camera was set up near the rear-view mirror in an experimental vehicle equipped with infrared lights, and it captured forward-facing images while both the headlights and the infrared lights were used to irradiate the road under the conditions shown in Fig. 6.

There were three pedestrians in front of the vehicle in the experiments. One stood on the left-hand side of the road and the others walked across the road. The distance from the

(a) Visible monochrome image

(b) Near-infrared image

(c) Visible region irradiated by headlights

(d) Invisible region that driver cannot see.

Fig. 8. A result of driver's visibility estimation

vehicle to the pedestrians was set at about 10, 40 and 50 meters, respectively.

Fig. 8 shows an example of the results of a visibility estimation experiment using our method. Fig. 8 (a) shows the visible image. Note that the nearest pedestrian (who was standing on the left-hand side of the road) was able to be detected, but it was difficult to recognize the other two people as they walked across the road. Fig. 8 (b) shows an infrared image that was captured at the same time. The distant pedestrians are also bright enough to be detected, since the infrared lights irradiate further than the headlights. The dark region in Fig. 8 (c) shows the region that is irradiated by the headlights. This corresponds exactly with the visible region for the driver, and the dark region in Fig. 8 (d) shows the difference between the regions irradiated by the headlights and by the infrared lights; this represents the region where it is difficult for a driver to see. From the results of the experiment, it could be confirmed that the two more-distant pedestrians would be more difficult for the driver to see when using headlights alone.

IV. Conclusion

A multiband camera has been developed that can capture both color images and infrared images simultaneously. The camera includes a special filter that modifies part of a Bayer filter array that is used in single-chip digital color cameras. It can acquire images covering four bands (red, green, blue and infrared) that have common optical axes and no time differences. Use of the camera can be shared among plural applications because it can provide various types of images.

A method for estimating a driver's visibility in the dark by applying the camera in a night-vision system is introduced in the paper, and its effectiveness has been confirmed by carrying out some experiments. If the proposed method and a pedestrian-detection technique were to be integrated, a nuisance-free alarm system could be achieved because it could recognize only those pedestrians that the driver is unable to detect using headlights alone. Moreover, a more effective adaptive lighting system could be realized if the proposed method is combined with a lighting-control technique.

Future work is aimed at realizing an effective driver assistance system such as this, and we would also like to develop some other novel techniques that make use of the differences between images covering multiple irradiation bands.

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