Development of an Advanced NIR Multispectral Technology Camera System with Potential Industrial and Medical Innovative Applications

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Abstract

We developed an advanced multi near-infrared (multi-NIR) spectral camera with an optimized vision system. A camera image system was developed that achieves high image quality and color reproduction by processing the image signals of six independent wavelengths into six kinds of pixels. Each pixel has three visible light regions and three NIR light regions. In the case of 0 lux, the motion image (30 fps) is constructed using the three NIR image signals only. With a small amount of visible light (0.001 lux or less), video color images with improved SNR can be reconstructed, compared to the conventional visible light image, by adding the color information of visible light and three NIR and using the brightness information. Another application of the multi-NIR camera system and algorithm is a fundus camera. The fundus camera provides a high SNR picture of the capillary blood condition in arteries at the fundus. A clear fundus image can be obtained by applying a deconvolution on a three-wavelength NIR image, which has reduced noise by integrating multiple images. In addition, it is reported that an optimized Fabry-Perot process technology can be applied to fine pixels. This is a cost-effective process manufacturing technique that is possible with two process masks used to manufacture Fabry-Perot structures for three bandpass filters (NIR and SWIR). A Bayer array bandpass structure is applied to 3×3 μm² Frontside Illumination (FSI) CIS and a 2×2 μm² pixel Backside Illumination (BSI) CIS.

1 Introduction

Multi-NIR cameras have been developing for many applications such as industrial, medical, and biology (agriculture) fields [1] [2]. One solution is to use organic material filters and to adjust the linear matrix for the camera processing to achieve multi-NIR spectral sensing in 1.12×1.12 μm² pixel size CIS [3]. However, the spectral response of this solution is not sufficient to achieve the clarity of color of a target scene. A Fabry-Perot bandpass filter (BPF), applied to the NIR in CIS, has been shown to provide excellent spectral response [3].

Innovative multi-NIR color processing is proposed that allows the mixing of the image parameters of the multi-NIR and RGB (Red, Green, and Blue) color (Fig.1). Excellent video images can be obtained under weak visible illumination as a result. Even under 0 lux conditions, a color image is obtained using the multi-NIR camera [4]. Further, a fundus camera for monitoring eye health, without dazzling, has been developed [5]. The advanced fundus camera system captures the fundus image and displays information on the eye and body health condition from the capillary blood in both veins and arteries.

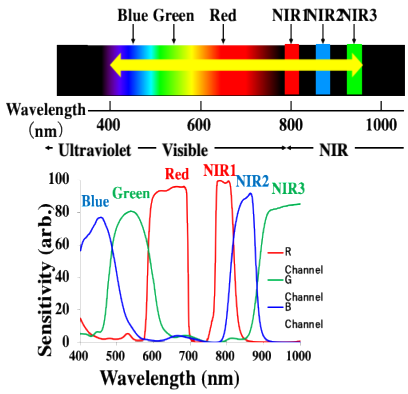

Fig. 1 Multispectral RGB + NIR1, NIR2, NIR3.

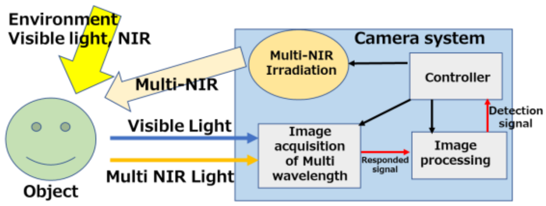

Fig. 2 Multi-NIR camera system.

2 Multi-NIR color image processing

The developed configuration of the entire multi-NIR camera system is shown in Fig. 2. This camera system is equipped with multi-NIR irradiation, an image acquisition system of multi-wavelength and image processing system to obtain high-quality imaging under a low visible light environment. The processing system is shown that achieves high image quality and color reproduction by processing the image signals of six independent wavelengths into six kinds of pixels (Fig. 3). And, this signal processing provides color-separated R, G, B responses to visible light only. An imaging response dispersed in a plurality of channels can be

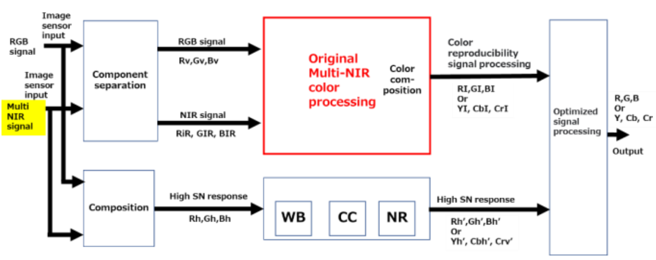

Fig. 3 RGB and Multi-NIR image processing system.

obtained in the wavelength band in the near-infrared region. Basic image processing functional configurations are shown in Fig. 3, where WB: White Balance, CC: Color Correction, and NR: Noise Reduction. Visible light and near-infrared light are independently adjusted for these images.

Next, the optimized image composition is described. Input two systems: a signal generated with an emphasis on gradation expressions such as color and brightness (color-oriented signal) and a signal generated with an emphasis on spatial quality such as SN-oriented signal. The SN-oriented signal is processed with priority given to no loss of detail information due to saturation, blackout, blurring, etc., rather than proper overall brightness expression. The spatial filter for noise reduction processing applied to the color-oriented signal or the additional signal reduces the high-frequency component due to noise. However, a low-pass filter that can retain the contour components of the processed image as much as possible is used. Color separation RGB response of normal visible light can be obtained. Further, in the wavelength band in the near-infrared region, it is possible to obtain an imaging response dispersed in a plurality of channels. In the case of 0 lux, the image is constructed using the three NIR image signals only.

With a small amount of visible light (0.1 lux or less), a color image with improved SNR can be constructed, compared to the conventional visible light image, by adding the color information of visible light and three NIR and using the brightness information. To prove the processing system, a very low noise full-color image was obtained with 0.03 lux (Fig. 4: reproduced image under only visible light condition and Fig. 5: using multi-NIR color image processing, very low noise image is obtained).

3 Innovative applications with multi-NIR camera

An example suitable for surveillance cameras, the results of the video with multi-NIR color image processing in the actual field environment are shown. It can be seen that a person can be identified by the effect of color processing in the result of multi-NIR in an environment of visible light intensity of 0 to 0.001 lux. In the case of this level of illuminance, color information from visible light cannot be obtained, so in the case of mono-NIR, only black-and-white luminance information can be obtained. Further, in the case of only the conventional visible light, it becomes a moving image in which almost nothing is captured. It can be seen that a camera system with multi-NIR color image processing can express colors that are easy to recognize even in low light conditions (Figs. 6 to 8). And the following is a result that makes it easy to determine a condition that is harmful to humans from a color image.

Fig. 9 shows that both water and alcohol are captured as pale red using the multi-NIR camera system, while kerosene and benzine are both colorless and transparent. Using only visible light, both images are colorless, transparent, and indistinguishable. This phenomenon is thought to occur

Fig. 4 Reproduced image without multi-NIR image signal.

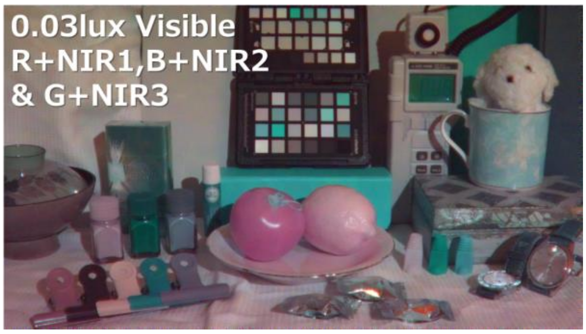

Fig. 5 Reproduced image with multi-NIR color image processing.

Fig. 6 Motion picture under environment condition

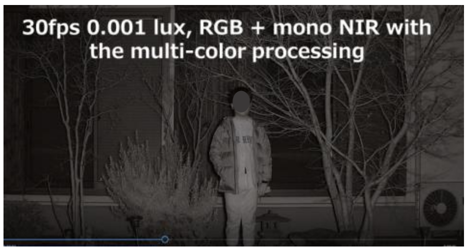

Fig. 7 Motion picture under environment condition with mono-NIR light condition

Fig. 8 Motion picture under environment condition with multi-NIR light condition

because H_2O absorbs light with a wavelength of approximately 940 nm (Fig. 10).

Further, this technology can identify frozen road surface conditions. As shown in Fig. 11 and Figs. 12 (a), (b) when the asphalt is frozen or melted ice condition, the road surface turns red. In the case of only visible light, both the frozen and water states are colorless and transparent, and whether the road surface is frozen cannot be determined. A dangerous condition can easily be identified as a color indicator in a beverage condition or frozen road conditions.

Another application of the multi-NIR camera system and algorithm is a fundus camera, which realizes eye health monitoring without dazzling [5]. A fundus camera provides a high SNR picture of the capillary blood condition in arteries at the fundus. After low noise processing with integrated images, a clear fundus image can be obtained by performing a deconvolution operation on a three-multi-NIR image as shown in Figs. 13 (a), (b). Further, in this observation of identified arteries and veins, a multi-NIR fundus camera with a stripe patterned illumination can be used to detect blood lipid concentration by scattered NIR from retinal blood vessels [6]. The advanced fundus camera system captures the fundus image and displays information on the eye and body health condition from the capillary blood in both veins and arteries [7].

4 Multi-NIR process technology

A spectroscopic technique with NIR reflected light with a sharp peak is developed using a bandpass filter (BPF) with multilayer interference in the NIR region. There is a specific transmitted wavelength in the BPF, and other wavelengths are reflected by the Fabry-Perot filter (Fig. 19).

A Bayer array bandpass structure was applied to 3×3 μm^2 a full HD Frontside Illumination (FSI) CIS and a 2×2 μm^2 pixel 5 mega Backside Illumination (BSI) CIS. Three types of NIR wavelengths were obtained as signals for each pixel. The cross-sections of the fabricated Fabry-Perot BPFs for BSI-CIS and FSI-CSI are shown in Fig. 17 and Fig.18, respectively. The bottom and upper stacks of the multilayer film, comprising multiple BPFs, are designed to sandwich the central film. The reproduced image in the 0 lux visible light condition is shown (Fig. 20). The fabrication process flow is shown in Fig. 14. Although the center layers' thicknesses for the three BPFs were controlled by lithography and etching, bottom and upper stacks for all BPFs were deposited simultaneously. Although we have shown a structure in which the center layer thickness with lower refractivity controlled the transmit wavelength [7], the controlling layer can be replaced by a higher refractive one (Fig.15). Furthermore, this structure can be extensively applied up to the SWIR region (Fig. 16)

5 Conclusion

The multi-NIR processing system has been developed that achieves high image quality and color reproduction by processing the image signals of six independent wavelengths into six kind of pixels. And innovative

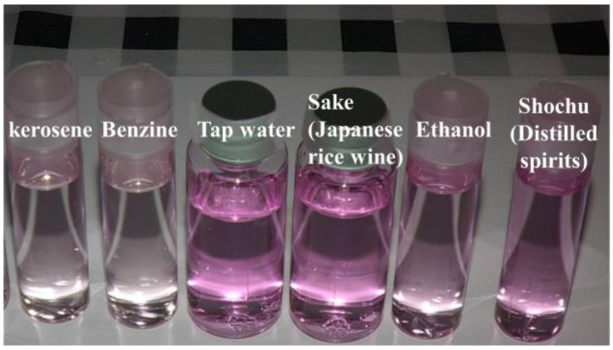

Fig. 9 Reproduced image by 3 multiple NIR.

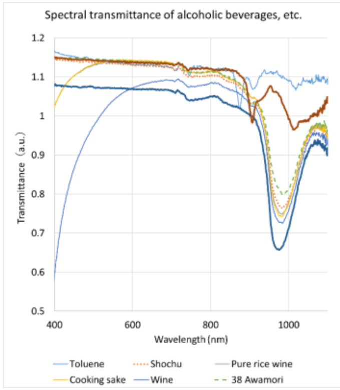

Fig. 10 Transmission spectroscopic characteristics of various alcohols.

Fig. 11 Reproduced image: RGB.

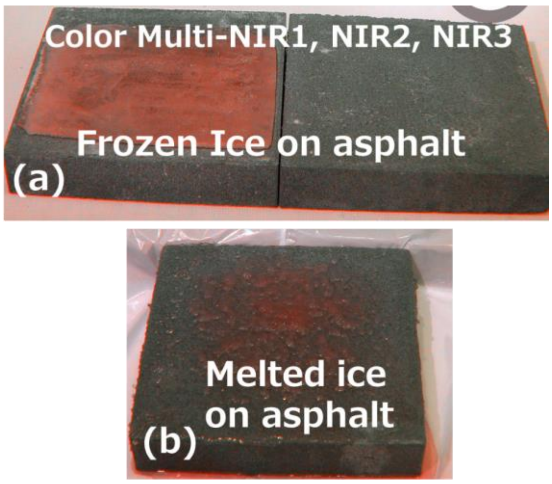

Fig. 12 Reproduced image: with 3 multiple NIR, (a) frozen condition and (b) melted ice condition.

applications with multiple near-infrared (multi-NIR) spectral CMOS image sensors (CIS) and camera systems have been demonstrated. In addition, multi-near infrared BPF process technology was developed using CMOS image sensor with fine pixel (<3×3 μm^2). This is a cost-effective process manufacturing technique that is possible with two process masks used to manufacture Fabry-Perot structures for three bandpass filters.

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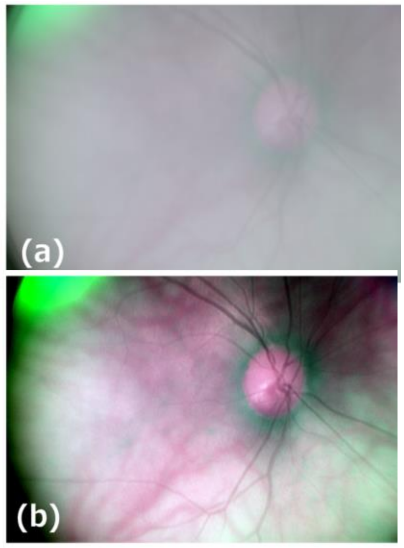

Fig. 13 (a) After low noise processing, and (b) After a deconvolution algorithm, captured excellent Fundus image by only 3 multiple NIR.

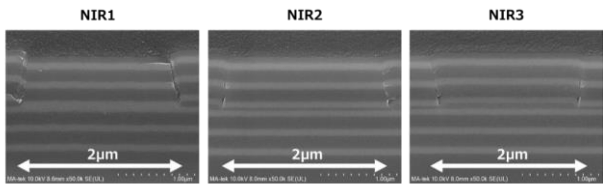

Fig. 17 Cross-sectional SEM 2μm sq. pixel BSI-CIS.

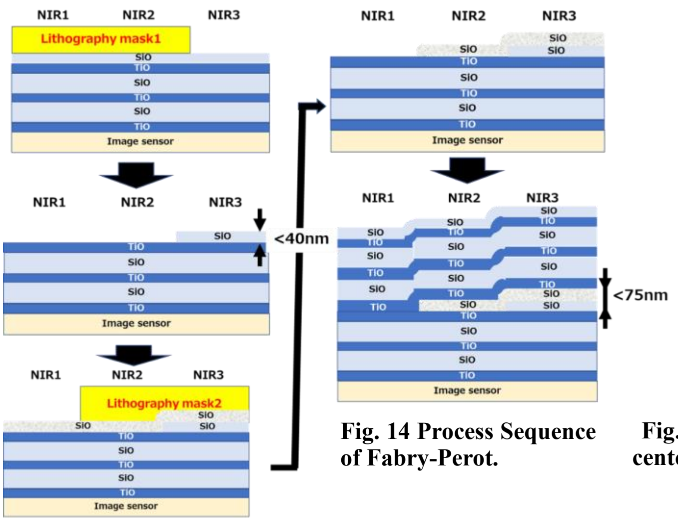

Fig. 14 Process Sequence of Fabry-Perot.

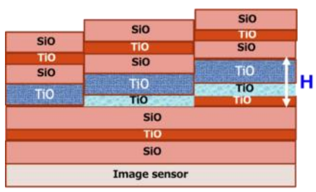

Fig. 15 This Fabry-Perot BPF is centered around a high refractive index TiO.

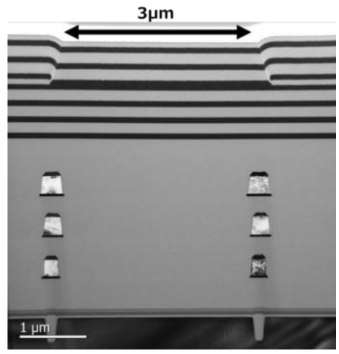

Fig. 18 Cross-sectional TEM 3μm sq. pixel FSI-CIS.

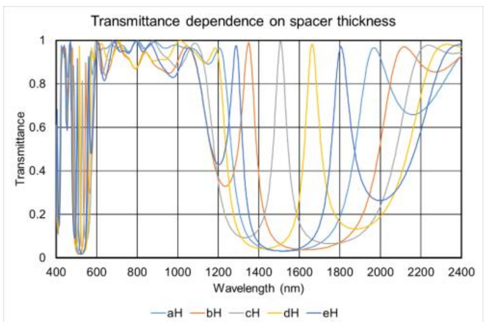

Fig. 16 The simulation results of SWIR wavelength BPF by Fabry-Perot structure.

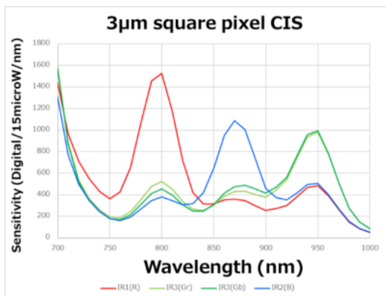

Fig. 19 Spectral response with Fabry-Perot 3 NIR sensitivity.

Fig. 20 Reproduced image in 0 lux.