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Near-infrared fundus camera with patterned illumination mask for lipid concentration determination based on light scattering from retinal blood vessels

Wang Ze[1], Masayuki Uemura[1], Hironari Takehara[1], Makito Haruta[1], Hiroyuki Tashiro[1, 2], Kiyotaka Sasagawa[1], and Jun Ohta[1]

[1] Nara Institute of Science and Technology,
8916-5 Takayama-cho, Ikoma, Nara 630-0192, Japan
Phone: +81-(743)-72-6051 E-mail: ohta@ms.naist.jp
[2] Faculty of Medical Sciences, Kyushu University,
3-1-1 Maidashi, Higashi-ku, Fukuoka 812-8582, Japan

Abstract

We developed a near-infrared (NIR) multispectral fundus imaging system that can acquire color images using NIR light instead of visible light. Aside from preventing eye irritation due to the use of visible light in conventional fundus cameras, the proposed NIR fundus camera with a stripe-patterned illumination mask can be used to detect scattering from retinal blood vessels, which can be used to determine blood lipid concentration, and thus, the health of an individual. Our simulation and experimental results revealed that we can obtain sharp and precise stripe illumination patterns of the fundus using our proposed fundus camera system, which proves its feasibility for scattered light detection from retinal blood vessels.

1. Introduction

A fundus camera is a complex optical system that enables observations of the interior of an eye; it can be used for diagnoses of several eye diseases by allowing retinal observations. Herein, we have developed a near-infrared (NIR) fundus camera that can be used to obtain a colorized image of the interior of a human eye using multispectral NIR images captured by it [1]. Because the human eye is insensitive to NIR light, compared with the conventional fundus camera, our proposed NIR fundus camera can avoid irritation of the eyes thereby making it easier to perform observations of the fundus. Furthermore, we developed a noninvasive method to evaluate the personal health of individuals in real-time by using the NIR fundus camera to detect blood lipid concentration in retinal blood vessels to diagnose lifestyle diseases, such as high blood pressure and obesity, because the occurrence of these diseases is closely associated with high concentrations of lipids in the blood.

2. Principle

Figs. 1(a) and (b) show the fundus images of the human eye obtained using the proposed NIR and conventional fundus cameras, respectively. As can be observed from these figures, the NIR fundus image obtained using our proposed fundus camera clearly shows the optic disk, which proves the efficacy of our fundus camera design. It has been reported that the intensity of the NIR light scattered by blood vessels is directly proportional to the lipid concentration in the blood

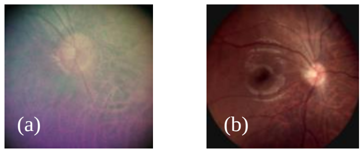

Fig. 1 Human fundus images. (a) NIR fundus image obtained using our proposed NIR fundus camera, and (b) visible-light fundus image obtained using a conventional fundus camera.

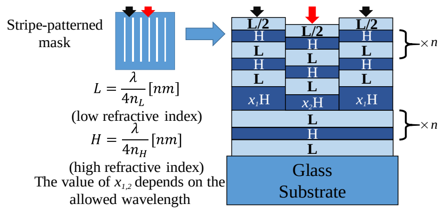

Fig. 2 Schematic structure of the patterned interference filter.

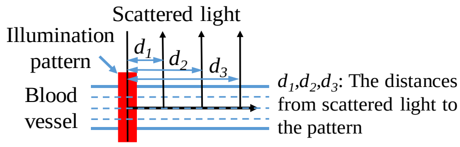

Fig. 3 Schematic diagram of scattered light.

[2]. Therefore, compared with conventional fundus cameras, aside from obtaining a fundus image, the proposed NIR fundus camera can be used to easily acquire blood composition information, such as its lipid concentration, by detecting the scattered light from a retinal blood vessel when subjected to patterned NIR light illumination. In particular, we applied a stripe-patterned light to illuminate a region of interest on the retina and detected the intensity of the scattered light by calculating the pixel intensity of the illuminated blood vessel in the fundus image.

We fabricated the patterned illumination mask included in our proposed fundus camera system using an interference filter (see Fig. 2). The patterned interference filter mask can simultaneously transmit light from two different wavelength bands. In particular, an 800-nm light was used for patterned illumination to obtain blood lipid concentration information, while an NIR light was used for wide-area retinal illumination. When the patterned light is incident on the blood vessel perpendicularly, the scattered light propagates along the blood vessel as depicted in Fig. 3. We selected the 800-nm light for patterned illumination because the absorbances of both oxygenated and deoxygenated hemoglobin are comparable at this wavelength. Thus, the impact of different absorbances of arteries and veins using light of other wavelengths can be avoided.

Scattering of incident light due to the tissues inside the human eye can cause blurring of a fundus image, which can pose problems in observing scattered light due to blood constituents such as lipid. Therefore, we applied a point-spread function (PSF) to eliminate this scattering effect.

The depth of spread and the medium are important properties that determine the PSF parameters, which, in turn, have a significant influence on the accuracy of the PSF [3]. After processing the obtained fundus image using the PSF, the intensity and distance of the scattered light propagating along the blood vessel can be suitably obtained. The intensity of this scattered light is related to the distance between the illumination and detection positions. The relationship between scattered light and these distances can be represented as follows [4]:

$$\ln[R(d) * d^2] = -\mu_{eff} * d + C, \qquad (1)$$

where d is the distance between the illumination and detection positions, $R(d)$ is the intensity of scattered light at the distance d, and C is a constant whose value is based on the medium properties. Furthermore, the slope of the abovementioned function μ_{eff} can be represented as follows:

$$\mu_{eff} = \sqrt{3\mu_a(\mu_a + \mu_s')}, \qquad (2)$$

where μ_a and μ_s' are the absorption and reduced scattering coefficients, respectively.

Using the abovementioned equations, we can obtain the relationship between μ_a and μ_s'; these two parameters indicate the concentration of lipids and other components in the blood. Therefore, based on these two parameters, the condition of our blood, and thus, our health may be inferred.

3. Simulation and experiment

Our simulation was conducted using an optical design software called ZEMAX. In our proposed NIR fundus camera design with patterned illumination, two lenses are present between the patterned interference filter mask and beam splitter; in particular, the patterned interference filter mask is placed right behind the second condenser lens. The system configuration used for the simulation and the simulation results are shown in Figs. 4 and 5, respectively.

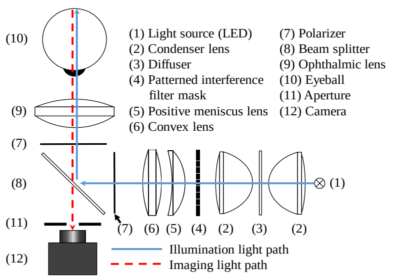

Fig. 4 Schematic diagram of our proposed fundus camera system.

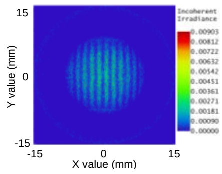

Fig. 5 Simulated illumination pattern on the retina. The widths of the lines of the illumination filter and the spaces between them are both 250 μm.

Furthermore, we also conducted a preliminary experiment wherein we applied a patterned metal mask in place of the patterned interference filter mask in our simulation to test the performance of the proposed NIR fundus camera in practice. The pitch and line widths of the patterned metal mask used in our experiment were 1 mm and 50 μm, respectively. First, we used a glass eye model to test the proposed NIR fundus camera. As shown in Fig. 6(a), the stripe pattern in the glass eye model was clearly captured by our camera system. Then, we applied the NIR fundus camera with patterned illumination to a human eye; the corresponding fundus image is shown in Fig. 6(b) wherein the stripe pattern and optic disk can be clearly observed. Thus, our simulation and experimental results prove the feasibility of our proposed NIR fundus camera for observing the interior of an eye and obtaining information regarding the blood composition of an individual.

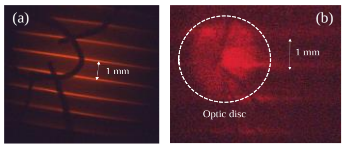

Fig. 6 Stripe patterns (a) in the glass eye model, and (b) in human eye fundus. The pitch and line widths on the mask are 1 mm and 50 μm, respectively.

4. Conclusions

In this study, we presented an NIR multispectral fundus camera design with a patterned illumination mask to detect light scattered by retinal blood vessels, which could provide an insight into the lipid concentration in the blood. The patterned illumination system developed in this study will be applied to our NIR fundus camera to detect scattering in blood vessels, which will be used to estimate lipid concentration.

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