Near-infrared transillumination imaging of veins using low-cost camera and scattering suppression - validation of practicality of developed system

Tran Trung Nghia, Phan Van To Ni, Tran Anh Tu, Kohei Yamamoto, Takeshi Namita, Koichi Shimizu

***Abstract*— Near-infrared (NIR) transillumination imaging is useful in many biomedical applications such as human biometrics and animal experiments. However, the image quality is generally poor due to the strong scattering in the body tissue. The authentication using the transillumination image of the palm vein and the finger vein is common these days, but there are some problems left such as misidentification and unidentifiability. To solve these problems with a simpler system than common ones, we have attempted to develop a biometric identification technique using the NIR transillumination and scattering suppression techniques. An array of LED's was placed at one side of the palm and a transillumination image was obtained with a low-cost CCD camera at another side of the palm. The image was processed by the deconvolution with the appropriate point spread function (PSF). The PSF was originally derived from the diffusion approximation of transport equation for the light source in turbid medium. We found that it can be applied for the scattering suppression in transillumination imaging of absorbing structure inside turbid medium. Even with the simple system, a clear vein image which was sufficient for authentication was obtained successfully.**

***Index Terms*— biometrics, near-infrared (NIR), transillumination, scattering suppression, deconvolution, point spread function (PSF), low-cost.**

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1 INTRODUCTION

The importance of transillumination imaging for blood vessels using near-infrared (NIR) light for medical and biometrics fields has been recognized [1-2]. In recent years, active study was conducted on the transillumination imaging for animal bodies [3]. This research field is still relatively new and not widely known in Vietnam due to the requirement of sophisticated and expensive hardwares.

NIR light with the wavelength of 700 - 1200 nm has relatively high transmission through biological tissue. Using the NIR transillumination imaging technique, we can visualize the blood vessels inside the tissue [2].

The authentication using the transillumination image of the palm vein or the finger vein is common these days. However, the observed image is severely blurred because of the strong scattering in the tissue, as the depth of the vessels increases. This is one of the major fundamental problems to cause misidentification and unidentifiability in personal authentication with transillumination images.

To overcome these problems, we developed the NIR transillumination technique using low-cost charge-coupled device (CCD) camera and a scattering suppression technique. This paper presents the experimental study to verify the feasibility of the proposed technique with a practical camera system.

2 SCATTERING SUPPRESSION TECHNIQUE

In previous study [2], the depth-dependent PSF was derived to describe the blurring phenomena by scattering for a fluorescent point source in a slab scattering medium. With a point source of light, we applied diffusion approximation to the equation of transfer and the spatial distribution of light intensity is given by,

$$PSF(\rho) = \frac{3P_0}{(4\pi)^2}\left\{(\mu'_s + \mu'_a) + \left[K_d + \frac{1}{\left(\rho^2 + d^2\right)^{1/2}}\right] \times \frac{d}{\left(\rho^2 + d^2\right)^{1/2}}\right\} \frac{\exp\left[-K_d\left(\rho^2 + d^2\right)^{1/2}\right]}{\left(\rho^2 + d^2\right)^{1/2}} \quad (1)$$

where $\kappa_d^{\ 2} = 3\mu_a(\mu'_s + \mu_a)$.

P_0, μ'_s, μ'_a, d, and ρ are the optical power of a point source, the reduced scattering coefficient, the absorption coefficient, the depth of a point source, and the radial distance in the cylindrical coordinate system, respectively.

This PSF was obtained as the light image from a point light source observed at the scattering medium surface. Therefore, its applicability to the transillumination image of an absorbing structure must be examined. In transillumination imaging, homogeneous light is irradiated from outside of the scattering medium. The scattered light goes through the absorbing structure and projects the shadow on the surface of the scattering medium. We can consider the absorber as a collection of light-missing points if the light is diffused well at the depth of the absorbing structure. Then the absorber image observed at the surface is the collection of the spread light-missing distributions which are the PSFs obtained above. We can apply the depth-dependent PSF to the transillumination image of an absorbing structure if this assumption is correct.

2.1 Applicability of light-source PSF to transillumination images of light-absorbing structure

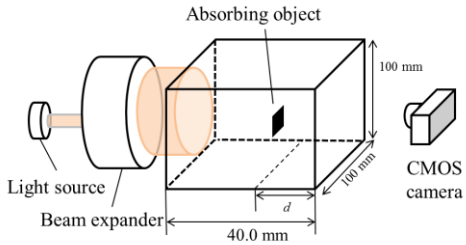


Fig. 1. Experimental setup for transillumination imaging: d = 4.00 - 14.00 mm

The applicability described above was assessed in an experiment. Fig. 1 shows the experimental system. As a scattering medium, an Intralipid suspension (Fresenius Kabi AG) was mixed with distilled water and black ink (INK-30-B; Pilot Corp.) to produce a tissue-equivalent medium (μ'_s = 1.00/mm, μ_a = 0.01/mm). As an absorbing structure, a square black-painted metal plate (10.0 mm × 10.0 mm × 1.00 mm) was used. This absorber was placed in an acrylic container (40.0 mm × 100 mm × 100 mm) filled with scattering medium. The depth of the absorber from the observation surface was variable from 4.00 to 14.0 mm. This phantom was irradiated with the NIR light from a laser (Ti: Sapphire, 800 nm wavelength) through a beam expander for homogeneous illumination. An image is obtained using a cooled CMOS camera (C11440-10C; Hamamatsu Photonics K.K.) oriented toward the opposite face of the phantom to the light-incident side.

The transillumination image of the absorbing object was obtained as the original with transparent medium or clear water. Subsequently, the transparent medium was replaced by the scattering medium. Then the transillumination image was obtained. The measured PSF for the absorbing structure h_{abs} was calculated as

$$h_{abs} = y \otimes x \quad (2)$$

where $\otimes$ denotes the deconvolution operation.

The measured h_{abs} was compared with the theoretical light-source PSF h obtained by using the same conditions as those of the experiment. Fig. 2 shows the comparison of PSF at depth d = 8.00 mm. Figs. 2(a), 2(b), 2(c), and 2(d) respectively show the observed transillumination image with the scattering medium y, with the transparent medium x, measured PSF for absorbing structure h_{abs} calculated from Eq. (2), and light-source PSF *h* calculated from Eq. (1). Fig. 3 shows the intensity profiles along the centerlines of Figs. 2(c) and 2(d). Fig. 2(c), 2(d) show good agreement between the measured PSF from Eq. (2) and the light-source PSF from Eq. (1).

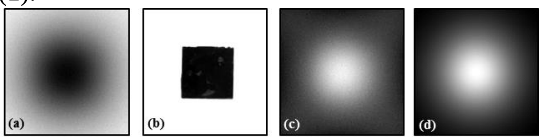


Fig. 2. Comparison of point spread function at depth d= 8.00 mm: (a) observed image with scattering medium, (b) observed image with transparent medium, (c) measured PSF from Eq. (2), (d) light-source PSF from Eq. (1)

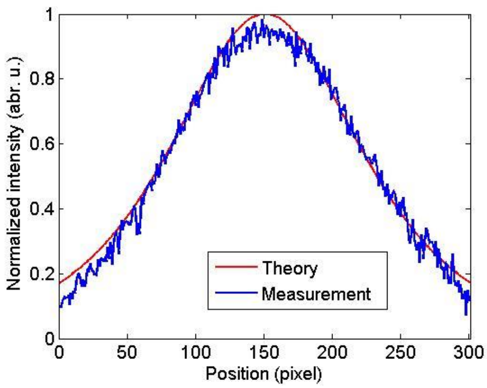


Fig. 3. Intensity profiles along the centerlines of Figs. 2(c) and 2(d)

Fig. 4 shows the result of the comparison in terms of the spread (FWHM) of these two PSFs. At the same depth d, both PSFs were in good agreement.

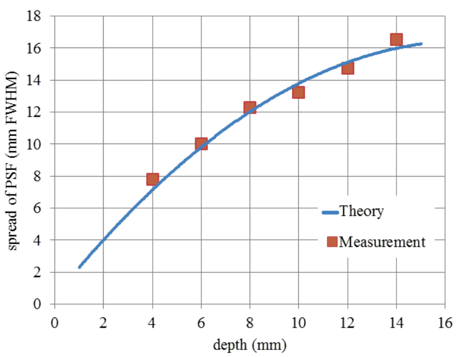


Fig. 4. Comparison between theoretical PSF for light source and measured PSF for absorber

Through this analysis, it was confirmed that the depth-dependent PSF for the light source is applicable to the transillumination images of the absorbing structure.

2.2 Validation by experiment with tissue-equipment phantom

The applicability of the proposed technique will be examined in experiment with chicken-breast meat. Fig. 5 shows experimental setup. As an absorbing structure, a black-painted metal plate (10.0 mm × 100 mm × 1.00 mm) was used. This absorber was placed at d=6.00 mm from the observation surface in an acrylic container (40.0 mm × 100 mm × 100 mm) filled with chicken-breast meat. This phantom was irradiated with the NIR light from a laser (Ti: Sapphire, 800 nm wavelength) through a beam expander for homogeneous illumination. An image is obtained using a cooled CMOS camera (C11440-10C; Hamamatsu Photonics K.K.) oriented toward the opposite face of the phantom to the light-incident side.

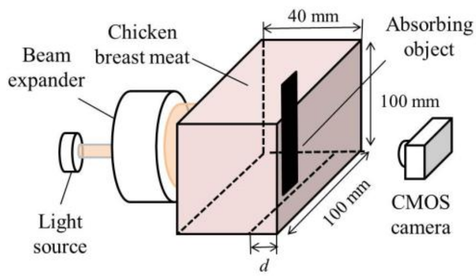


Fig. 5. Experimental setup for transillumination imaging: d = 6.00 mm

Fig. 6(a) shows the restored image by using the proposed technique. Fig. 6(b) shows the observed image. Fig. 6(c) shows the intensity profiles along the dashed lines of the images shown in Fig. 6(a) and 6(b).

The measured widths of the absorber in the restored images of the proposed technique and the non-invert technique in terms of the FWHM are 11.8 mm and 16.5 mm, respectively. As shown in the Fig. 6, the effectiveness of the proposed technique was confirmed.

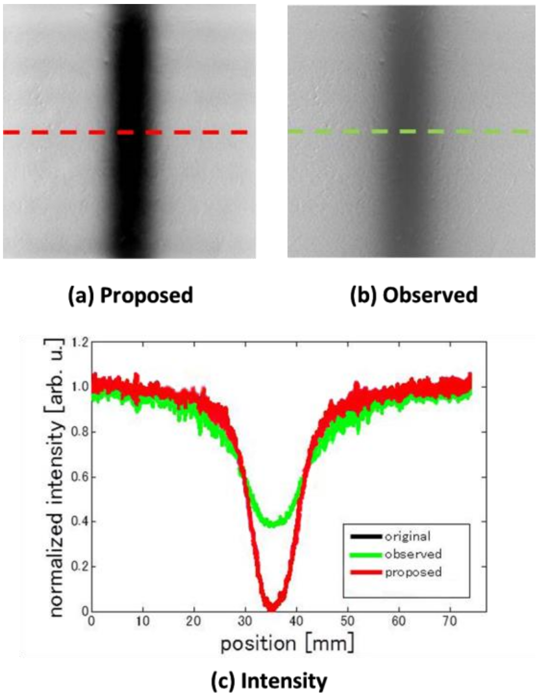


Fig. 6. Result with transillumination image of the absorber at d = 6.00 mm. The intensity profiles show the distribution of light intensity along the dashed lines. (μ'_s=1.00/mm, μ_a=0.01/mm)

This PSF is applicable to suppress the scattering effect of light-absorbing structure in transillumination imaging [4] as well as the light emitting source in turbid medium. However, we have to know the depth information of the structure to calculate the PSF. When we deconvolute a transillumination image using the PSF with a specific depth di, the part of the image that came from the depth di can be restored correctly. The other parts of the image from different depths are incorrect but they are generally blurred or made smaller than true size of the absorber. Therefore, we calculate the new projection image as,

$$P(x,z\,|\,\theta)=\sum_{i=1}^{n}\int A(x,y,z\,|\,\theta)dy \otimes PSF(x,z\,|\,d_i) \tag{3}$$

where P, A, and PSF respectively represent the functions of projection, blurred absorption distribution and point spread function. ⊗ denotes the deconvolution operation. (x,y,z), θ, and d_i respectively represent the Cartesian coordinates, orientation of observation, and the i-th depth, respectively. i = 1, 2 ...n, and n is the number of different depths.

3 Materials and Methods

3.1 Materials

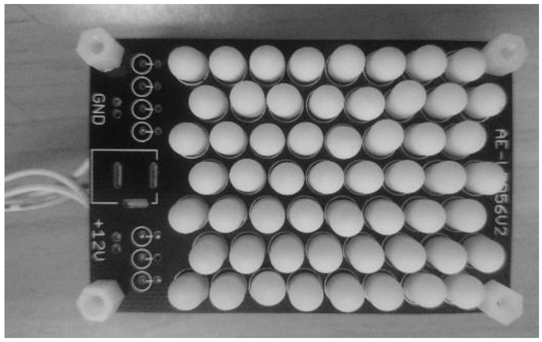


Fig. 7. LED array with diffuser

In transillumination imaging for biometrics, a high-intensity light source with homogeneous sensitivity over wide-area is required to illuminate a human palm. We arranged 56 NIR-LED’s (5.00 mm x 4.10 mm Oval Infrared, 940 nm wavelength, OSI5LA5453B, Opto Supply Lt.) in an 7 x 8 array on a circuit board of 72 mm x 46 mm. The diameter of each LED was as small as 5.00 mm and has a diffuser cap on its head to make the homogeneous light source as much as possible. Fig. 7 shows the appearance of the LED array.

The transillumination image was obtained with a simple CCD camera (MK-0323E B/W board camera) at another side of the human palm. The NIR high-pass filter (780 nm) was used in front of the camera to reduce optical noises and improve the image quality. Fig. 8 shows the CCD camera we used in this experiment.

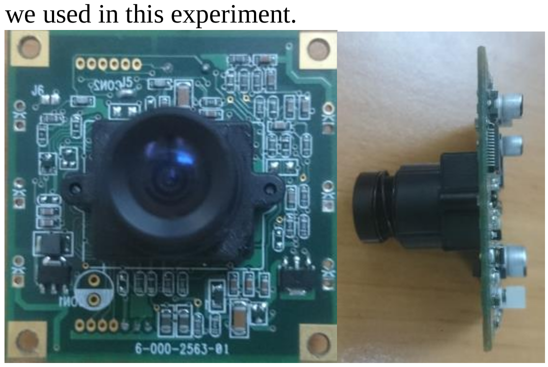


Fig. 8. CCD camera

3.2 Methods

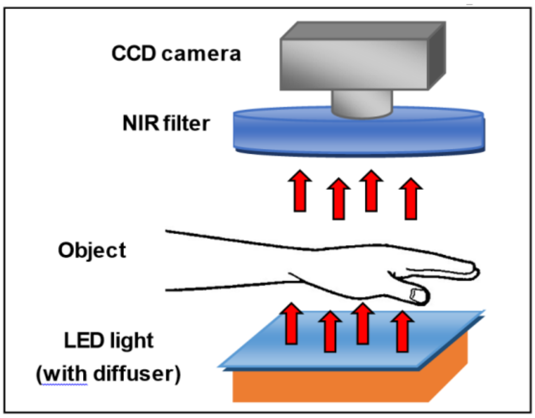


Fig. 9. Schematic experimental system

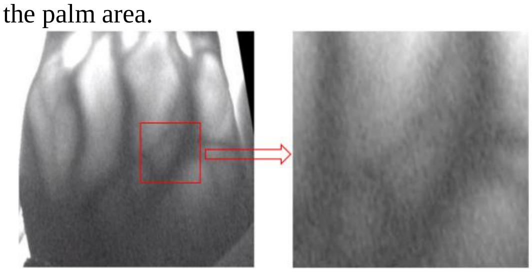
Fig. 9 shows the schematic of the experimental system to obtain a transillumination image of finger veins and palm veins. Fig. 9 shows the experimental system. The light source illuminated the palm from one side and the image was recorded with the CCD camera from another side. The image signal from the CCD camera was captured using a video capture module, which was connected with a personal computer.

The observed transillumination image deteriorated by scattering can be significantly improved using appropriate PSF of the scattering suppression technique mentioned above [2, 3].

Fig. 10. Experimental system

4 RESULT

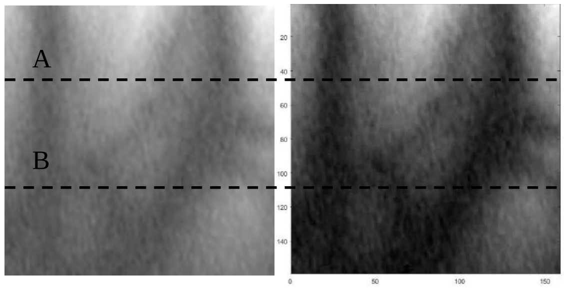
Fig. 11 shows the result of transillumination imaging of an adult palm. Among 4 volunteers in this study. The surface veins were hardly recognized in the subject with dark skin color. Fig. 11(a) is the NIR transillumination image of the palm area.



(a) (b)

Fig. 11. Result of transinllumination imaging: (a) observed image, (b) ROI image

Because the contrast of the image is not uniform, it is difficult to use whole area for further analysis. Fig. 11(b) is the region of interest (ROI) we chose for the analysis. The depth of the vein axis was assumed to be 4 mm from the skin surface.



(a) (b)

Fig. 12. Result using the proposed technique: (a) original image, (b) deconvoluted image at 4mm

Fig. 12(a) and 12(b) show the observed transillumination image and the result of deconvolution with the PSF at 4.00 mm depth. The observed image was degraded severely by the effect of strong scattering. The effect was greatly suppressed by the proposed technique, and the image of the veins was clarified.

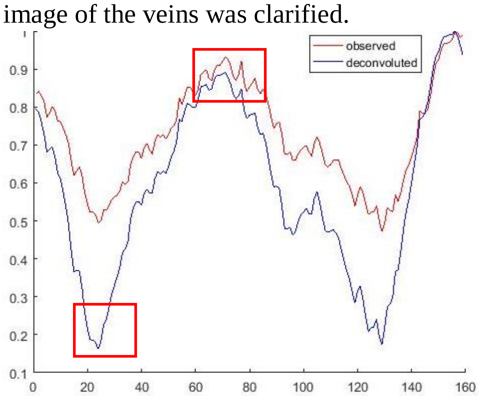


Fig. 13. Intensity profiles along line A in Fig. 12

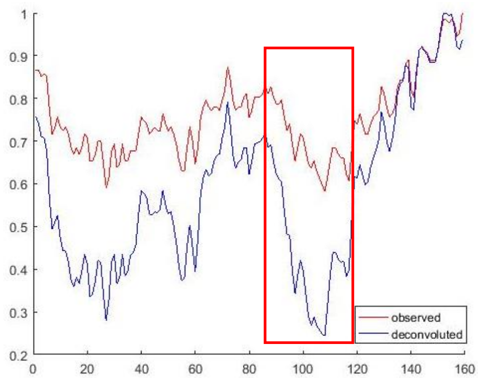


Fig. 14. Intensity profiles along line B in Fig. 12

Fig. 13 and 14 shows the intensity profiles along the horizontal lines A and B in Fig. 12, respectively. They apparently show the clarity enhancement of the vessel image. The Michelson contrast was improved from 0.34 to 0.69 and from 0.18 to 0.52 in Fig. 13 and 14, respectively.

Through this experimental analysis, it was confirmed that the PSF originally derived for a fluorescent light source is applicable and effective to suppress the scattering effect in the transillumination image.

5 CONCLUSIONS

Using a near-infrared light source and a low-cost CCD camera, the transillumination image of the palm was obtained and the vessels were visualized. The effectiveness of the scattering suppression technique was confirmed in experiment. The results suggested that even with a low cost CCD camera we can obtain the transillumination image sufficiently clear for personal authentication. This technique is also useful for noninvasive three-dimensional reconstruction of vein structure. It is useful for diagnosis and treatment in medical practice as well as biometric applications.

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Chụp ảnh mạch máu bàn tay bằng kỹ thuật chụp ảnh truyền qua sử dụng ánh sáng hồng ngoại gần và camera an ninh

Trần Trung Nghĩa, Phan Văn Tô Ni, Trần Anh Tú, Kohei Yamamoto, Takeshi Namita, Koichi Shimizu

***Tóm tắt*—** Kỹ thuật chụp ảnh hồng ngoại gần (NIR) truyền qua rất hữu ích trong nhiều ứng dụng y sinh học cũng như sinh trắc học trên người và các thí nghiệm trên động vật. Tuy nhiên, chất lượng hình ảnh nói chung bị ảnh hưởng rất lớn do sự tán xạ mạnh mẽ trong mô sinh học. Mặt khác, kỹ thuật nhận dạng bằng cách sử dụng hình ảnh các tĩnh mạch lòng bàn tay và tĩnh mạch ngón tay khá phổ biến, nhưng vẫn có một số vấn đề còn tồn tại như nhận dạng sai, lỗi hoặc không nhận dạng được. Để giải quyết những vấn đề này chúng tôi thiết kế một hệ thống đơn giản hơn các hệ thống phổ biến hiện nay, đồng thời cố gắng để phát triển một kỹ thuật sinh trắc học bằng cách sử dụng phương pháp chụp ảnh truyền qua sử dụng ánh sáng hồng ngoại gần và kỹ thuật xử lý giảm tán xạ. Một ma trận LED được đặt ở một bên lòng bàn tay và một hình ảnh truyền qua được ghi lại bằng một máy ảnh CCD giá rẻ ở phía còn lại của bàn tay. Hình ảnh được xử lý bằng cách giải chập với hàm lan truyền điểm (PSF) phụ thuộc độ sâu (bắt nguồn từ phương trình khuếch tán xấp xỉ của nguồn sáng trong môi trường mô sinh học). Chúng tôi thấy rằng nó có thể được sử dụng cho việc làm giảm sự tán xạ trong hình ảnh truyền qua của cấu trúc hấp thụ bên trong môi trường tán xạ mạnh. Kết quả của bài báo đã cho thấy hiệu quả và khả năng ứng dụng kỹ thuật chụp ảnh truyền qua và phương pháp khử tán xạ.

***Từ khóa*—** biometrics, near-infrared (NIR), transillumination, scattering suppression, deconvolution, point spread function (PSF), low-cost.