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# New Reconstruction Technique for 3 Dimensional Structure in Shallow Layer of Turbid Medium using Optical Transillumination Images - Attempt for Reconstruction with Limited View Angle -*

Taiki Matsuura, Takeshi Namita, *Member, IEEE*, Yuji Kato,
and Koichi Shimizu, *Senior Member, IEEE*

***Abstract*— In transillumination imaging of an animal body with near-infrared light, the shallower structure appears clearer. Therefore, we can reconstruct the three dimensional (3D) image of the shallow structure using the transillumination images as the projection images. In the 3D reconstruction, it may be better to use the projection images of limited observation-angle range rather than those from 360° range. We investigated this possibility and devised a new technique to reconstruct the 3D image of the light absorbing structure in shallow region of a turbid medium. This technique is applicable to the turbid object without any a priori knowledge on the angular position of the absorbing structure. The feasibility of the proposed technique was verified in experiments.**

## I. Introduction

The near-infrared light with 700–1200 nm wavelength has high permeability through animal tissue. We can obtain transmitted light even with the human forearm with 50–60 mm thickness. If we consider the transillumination images as the projection images, we may be able to reconstruct the three dimensional (3D) internal structure using the reconstruction algorithm of the X-ray CT. However, in optical transillumination imaging, the deeper structure appears more blurred due to the strong scattering. It is generally difficult to clearly visualize the light absorbing structure more than several millimeter depth in the human body tissue. It has been thought that we cannot reconstruct the 3D image by simply backprojecting the transillumination images with near-infrared light.

To overcome this difficulty, we developed scattering suppression techniques and have attempted the 3D reconstruction of the internal structure in a turbid medium [1–3]. These techniques, however, were not suitable to the animal body with more than 40 mm diameter in cross section. The usefulness would become much greater if we could visualize the 3D structure inside the larger animal body even only in shallow region. Thus, we have developed a new technique to obtain the 3D structure in shallow region of the larger turbid object using the transillumination images. In this paper, we present the principle of the proposed technique and the result of experiment to verify its feasibility.

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T. Matsuura (phone: +81-11-706-7229; fax: +81-11-706-7219; tmatsuura @bme.ist.hokudai.ac.jp), T. Namita (tnamita@bme.ist.hokudai.ac.jp), Y. Kato (kato@bme.ist.hokudai.ac.jp), and K. Shimizu (shimizu@bme.ist. hokudai.ac.jp) are with the Graduate School of Information Science and Technology, Hokkaido University, N14, W9, Kita-ku, Sapporo 060-0814 JAPAN

## II. Principle

### A. Scattering Suppression

In the light transmitted through animal body, there are two components. They are the weakly scattered light (WSL) and the strongly diffused light (SDL). If we can extract the WSL component from the transmitted light, the blurring effect of scattering can be suppressed.

Fig. 1 shows the principle of this scattering suppression [2]. Fig. 1(a) shows the spatial distribution of the transmitted light intensity at the observation surface of a slab turbid medium when a beam of light is illuminated on another side of the slab. We define the spatial intensity distribution of the transmitted light in this case as $I_1(x,y)$. Next, we install a diffuser plate on the incident side of the scattering medium, as presented in Fig. 1(b). We define the spatial intensity distribution of the transmitted light in this case as $I_2(x,y)$. With the diffuser, the incident light is deflected to random directions, and the forwardly propagating WSL component becomes greatly less in $I_2(x,y)$ than $I_1(x,y)$. On the contrary, the SDL component becomes moderately more in $I_2(x,y)$ than $I_1(x,y)$. The change in the WSL component is dominant in the change of output light through the scattering medium. Therefore, we can extract the WSL component $I_{WSL}(x,y)$ by subtracting $I_2(x,y)$ from $I_1(x,y)$ with an appropriate weight $\alpha$ [2,3] as

$$I_{WSL}(x,y) = I_1(x,y) - \alpha I_2(x,y). \quad (1)$$

### B. Reconstruction with Limited View Angle

In the algorithm of an X-ray CT (filtered backprojection, FBP), a cross-sectional image is reconstructed using the projection images from 360° directions. This method is based on the assumption that clear images of all the depths are obtained for all the directions. It does not hold in the case of

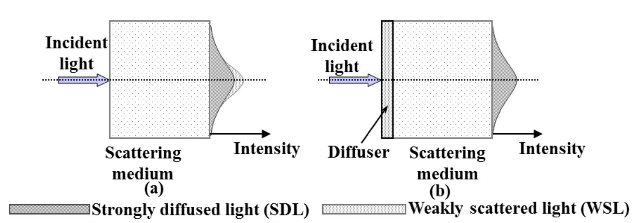



Figure 1. Principle of scattering suppression to extract weakly diffused light: (a) without diffuser, (b) with diffuser.

transillumination images blurred by the strong scattering. When a light absorbing object is close to the light illumination side, or deep from the observation surface, the transillumination image of the object is severely blurred. Therefore, if we use the transillumination images of all 360° directions, we have to use many blurred images. This makes the reconstruction of clear cross-sectional image difficult. This is the distinct difference from the X-ray CT [4]. In the case of X-ray, projection images are similarly clear in any directions. Therefore, the clearer image can be reconstructed as the number of the directions of the projection data increases. This does not hold in the case of optical transillumination images. The reconstructed cross-sectional image becomes worse if severely blurred transillumination images are used as the projection data rather than the case without using them. Therefore, we limit the viewing angle to eliminate the undesirable directions of the transillumination images.

However, in this principle, we have to know the orientation in which the shallow absorber becomes close to the observation surface. Then, this technique cannot be applied to the object with unknown inside structure. To overcome this problem, we devised the following solution.

1) Select the height or the plane of CT reconstruction.

2) Divide the view angle 360° into some limited angle regions. For example, we can make 4 regions of the view angle limited to 90°.

3) Choose one of the angle regions and reconstruct the cross-sectional image using the transillumination profiles at the selected height using the images observed in the limited view angle region. The cross-sectional image extends over 360° angle making a circle.

4) Cut out a sector of the cross-sectional image from the circle. The position of the sector in the circle corresponds to the angle region chosen in the process 3).

5) Repeat the processes 3)–4) until the cross-sectional sectors are obtained for all the angle regions. If we divide the view angle into four 90° regions, we obtain 4 sectors of the cross-sectional image.

6) Combine all the sectors into a circle by putting the sector patch in the position of the corresponding angle region.

In this way, we can obtain a clear cross-sectional image of the shallow absorbing structure in all the directions, even when the positions of the inside structure is completely unknown in a turbid medium. We repeat this cross-sectional imaging in a horizontal plane while changing the imaging height of the turbid medium. Finally, we piled up the horizontal cross-sectional images in a vertical direction, and construct the 3D image of the absorbing structure in a turbid medium.

## III. Experimental Verification

### A. Method

The effectiveness of the proposed technique was examined in experiments. Fig. 2 shows the experimental setup schematically. To simulate the surface vein in the forearm, turbid solution ($\mu'_s = 1.0$ /mm) was contained in a cylinder (56 mm$\phi$) made of transparent acrylic resin, and a cylindrical post (5 mm$\phi$) painted black was placed 5 mm from the inner wall of the container. To avoid the effect of refraction, the cylindrical container was placed in a tank (rectangular parallelepiped) filled with glycerol to match the refractive index. As a light source, the laser (Ti:Sapphire, 800 nm wavelength) was used. A beam of the laser light was expanded to 27 mm$\phi$ by a beam expander and illuminated one surface of the tank. The transillumination image was recorded with a cooled CMOS camera from the other side of the tank. After recording a transillumination image, $I_1(x,y)$, an opal diffuser plate (1% transmission) was inserted on the illumination side of the tank wall and the image $I_2(x,y)$ was recorded. Using (1) the image with the scattering suppression $I_{WSL}(x,y)$ was obtained.

This operation was repeated 360 times while rotating the cylindrical container by 1° and 360 $I_{WSL}(x,y)$ images were obtained. We set the subtraction weight in (1) as $\alpha = 0.7$. The cross-sectional image in a horizontal plane was reconstructed using the transillumination images in a limited view angles as mentioned in Section II. B. We applied the binarization process to the cross-sectional image and constructed the 3D image.

### B. Effect of View Angle Limitation

The effect of limiting the view angle was examined. Fig. 3 shows the transillumination images of a cylindrical absorber in a turbid medium. The depth of the absorber, or the distance from the observation surface was 5 mm. The image deteriorated by scattering could be apparently improved by the scattering suppression technique in Section II. A. The position and the shape of the absorber became recognizable. This scattering suppression process was applied to all the 360 transillumination images. Using the images of limited view angles, we reconstructed the cross-sectional image by FBP method. Finally, the 3D image was reconstructed using the cross-sectional images of different heights.

Fig. 4 shows the result of the 3D reconstruction. Fig. 4(a) is the image reconstructed when the turbid medium was replaced by clear water. Fig 4(b) is the image reconstructed from the transillumination images viewed from all 360°. In this case, there were blurred images involved in the reconstruction, and the reconstructed image was apparently blurred. Figs. 4(c)–4(f) show the images reconstructed from the transillumination images with the limited view angles of 180°, 120°, 90° and 60°. By limiting the view angle to 180°–90°, the images became clearer. If we limit the angle too much such as to 60°, the accuracy of the reconstructed image became low.

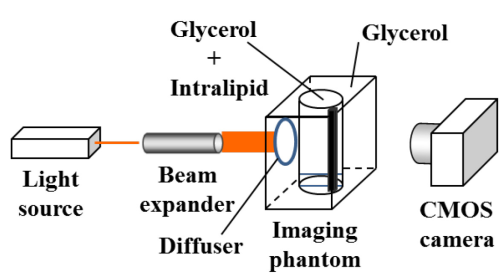



Figure 2. Measurement system.

In this analysis, the effectiveness of limiting view angle was confirmed. In addition, it was found that the 90° limitation is effective for the shallow absorbing structure in a turbid medium of examined size, or the veins in the adult forearm.

### C. *3D Reconstruction of Unknown Structure*

The effectiveness of the proposed technique was examined for the case in which the internal structure of the turbid medium is unknown. In the experiment, three absorbing posts were placed in the cylindrical turbid medium with 56 mm diameter. They were a circular cylinder, triangular prism and a quadrangular prism. The horizontal cross-sections of them were a circle (5 mm$\phi$), an equilateral triangle (10 mm side) and a square (10 mm side), respectively. As shown in Fig. 5(a), they were placed at the positions of 12, 3, 9 o'clock and 5 mm far from the surface of the cylindrical turbid medium. We divided the 360 transillumination images from all 360° directions into four groups of 90° angular regions. The cross-sectional images reconstructed from the transillumination images of each angular region are shown in the left part of Fig. 5(c). From the cross-sectional images, the sectors at the corresponding angular regions were cut out and put together into a single cross-sectional image.

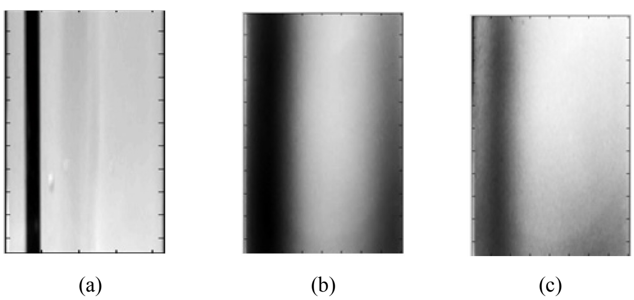



Figure 3. Transillumination images: (a) observed image in transparent medium, (b) observed image, (c) improved image.

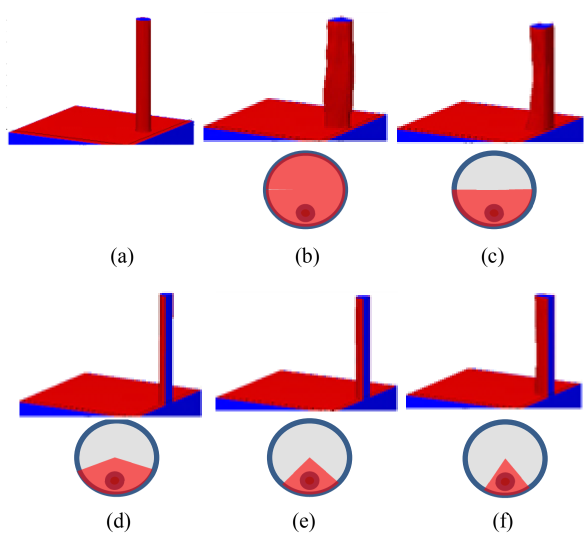



Figure 4. 3D images reconstructed with; (a) 360° transillumination images in clear water, (b) 360°, (c) 180°, (d) 120°, (e) 90°, (f) 60° transillumination images in scattering medium.

For comparison, the cross-sectional image reconstructed from all 360 transillumination images is shown in Fig. 5(b). In this figure, the existence of the absorbers was recognized, but the shape of the absorber was indistinguishable. In contrast, the shapes became distinguishable in the image obtained by the proposed technique. Fig. 6 presents the 3D images obtained from these cross-sectional images. The characteristics of the cross-sectional images were apparent in the 3D images, as well. In other words, we can reproduce the 3D structure with accurate cross-sections using the proposed technique.

In the above example, we set the dividing line for the limited view angle regions to pass between the absorbers as shown in Fig. 5(a). In practical applications, the positions of absorbers are often unknown. So, we examined the dependence of the reconstructed image on the difference of this division. Fig. 7 presents the positions of the dividing lines and the 3D images reconstructed. When the dividing line intersects the absorber (Fig. 7(b)), the outline of the reconstructed image became somewhat irregular. However, even in this worst case, the structure and the cross-sectional shapes were sufficiently recognizable. Through these analyses, the effectiveness of the proposed technique even for the turbid object with unknown internal structure was verified.

## IV. CONCLUSION

For the 3D non-invasive imaging of shallow regions of a human body, we have developed a new technique to reconstruct the absorbing structure from optical transillumination images. In this technique, we apply the scattering suppression method to obtain a clear image of the

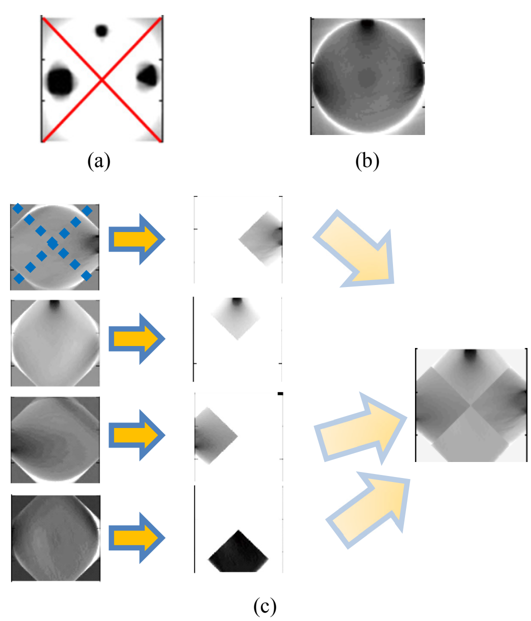
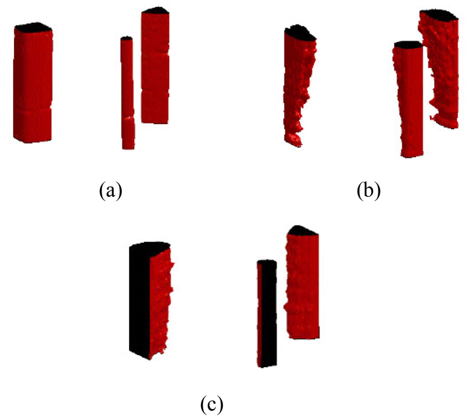


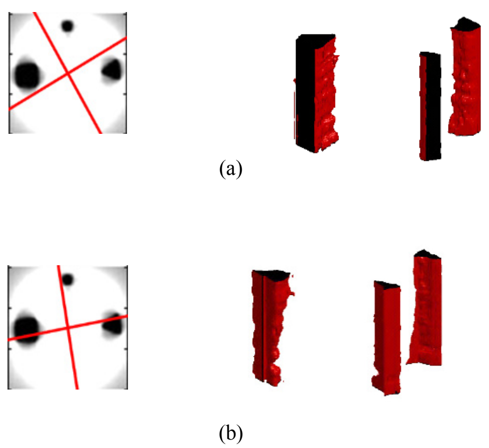

Figure 5. Result of view angle limitation: (a) cross-sectional image in clear water and dividing lines, (b) image from 360° projections in scattering medium, (c) image from 90° projections in scattering medium and patchwork.



(a) (b)

(c)

Figure 6. Effectiveness of view angle limitation in 3D reconstruction with; (a) 360° transillumination images in clear water, (b) 360° transillumination images in scattering medium, (c) 90° transillumination images in scattering medium.



(a)

(b)

Figure 7. Effect of dividing position for view angle limitation.

absorbing structure by extracting the weakly scattered light component from the strongly diffused light. The cross-sectional image was reconstructed from the transillumination images by the FBP algorithm. In this reconstruction, we do not use the projection of the blurred images by selecting the transillumination images of a limited view angle region. In this way, the 3D imaging of internal structure became possible even with the turbid medium such as an animal body. The effectiveness of the proposed technique was verified in the experiment using the model phantom that simulates the veins in the human forearm. Further, we extended the technique so that we can apply it to the turbid medium with unknown internal structure. In experiments, the applicability and the usefulness of the proposed technique to the unknown structure were verified. These results suggest the possibility to obtain the 3D image of shallow blood vessels about 5 mm depth in the body with the thickness of 50–60 mm such as an adult forearm. This ability should be useful for medical applications concerning the major blood vessels in the human forearm.

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