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RECONSTRUCTION OF CROSS-SECTIONAL IMAGE OF DIFFUSE MEDIUM USING BACKSCATTERED LIGHT

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1. Introduction

The near-infrared light of 700-1200 nm wavelength has high transmission through a human body. However, there is a strong scattering in the body tissue and it is difficult to obtain the image of the internal structure of our body. Recently there has been an increasing interest in the study of light propagation in dense random media to realize an optical CT [1,2].

In the optical CT, two types of light-detection schemes have been used. One detects the transmitted or forwardly scattered light, and another the backwardly scattered light (here we call it a backscattered light). Using the transmitted light, we can have the whole cross-sectional image of the subject. But the thickness of the subject has to be thin enough to get the transmitted light. Using the backscattered light, we can obtain the cross-sectional image of only a certain part near the surface of the subject. However, the applicability of this technique is not restricted by the thickness of the subject. In the combination with optical fibers, it is particularly useful in the clinical applications, such as the imaging of inner walls of digestive tracts, blood vessels and heart chambers.

We have developed a new technique to reconstruct the cross-sectional image of diffuse medium using the backscattered light. This paper presents the basic idea of this technique and some results of a computer simulation.

2. Principle

Fig.1 shows the arrangement of the light incidence and the detection of a backscattered light. In practice, they are realized by the optical fibers in

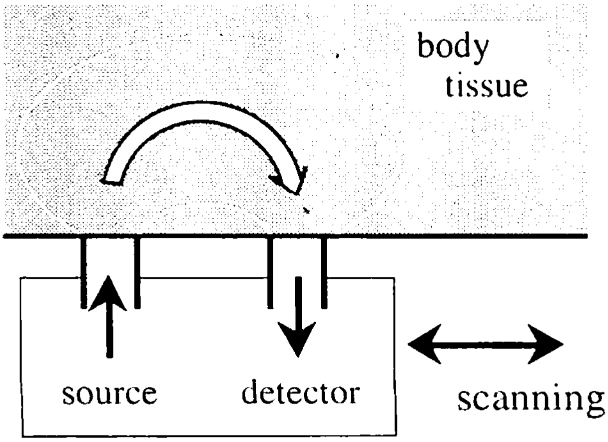


Fig. 1 Light incidence and detection.

close contact with the body tissue to illuminate a light and to guide a backscattered light to a photodetector.

In this technique, the cross-sectional image of a subject is reconstructed in two processes. In the first process, we obtain the absorbance distribution in the depth-direction of the subject using the principle described below. In the second process, we scan the pair of two optical fibers along the surface of the subject to obtain the horizontal variation. By combining these two processes, we can reconstruct the cross-sectional image of the subject in the same way as the B-mode scan in an ultrasonic imaging.

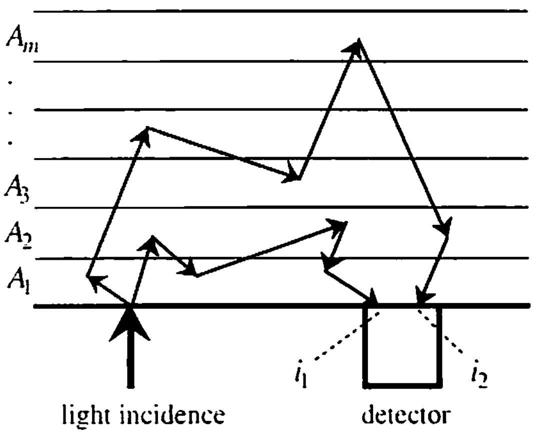


Fig. 2 Principle of measurement.

Fig.2 illustrates the principle to obtain the depth-distribution of the absorbance. We follow the general manner of the Monte Carlo technique [3,4] to simulate the light scattering and absorption in random media. The word "photon" here represents a group of photons that propagate in the medium as if they are a particle with a certain optical power to be attenuated in the propagation.

In Fig.2, j-th photon with a unit power is injected and reaches to a detector in the time t_j after some collisions against scatterers. Then, the optical power reached in the detector is given by,

$$i_j(t_j) = \exp\left\{-\left(A_1 d_{1j} + A_2 d_{2j} + \cdots + A_m d_{mj}\right)\right\} \qquad (1),$$

$$t_j = \left(d_{1j} + d_{2j} + \cdots + d_{mj}\right)/c \quad .$$

where $A_1, A_2, \cdots, A_m$ are the absorption coefficients of the 1st, 2nd, ... m-th layers, $d_{1j}, d_{2j}, \cdots, d_{mj}$ are the distances in which the j-th photon propagates in the 1st, 2nd, ... m-th layers respectively, and c is the velocity of light in the medium. Under the condition of $A_1 d_{1j} + A_2 d_{2j} + \cdots + A_m d_{mj} \ll 1$, we can apply a linear approximation, and get

$$i_j(t_j) \approx 1 - \left(A_1 d_{1j} + A_2 d_{2j} + \cdots + A_m d_{mj}\right) \qquad (2).$$

Since the incident impulse of light is considered as a collection of many photons, the detected intensity is expressed as,

$$I(t) = N(t) - \{A_1 D_1(t) + A_2 D_2(t) + \cdots + A_m D_m(t)\} \qquad (3),$$

where $N(t)$ is the number of photons detected at the time t.
$D_k(t) = d_{k1} + d_{k2} + \cdots + d_{kN(t)}$ is considered to be the probability of the photon propagation in the k-th layer.

The set of distances $\{D_k(t)\}$ depends on the scattering property of the tissue but is almost independent of the absorption property. Therefore, if we know the $\{D_k(t)\}$ a priori, we can obtain the set of unknowns $\{A_k\}$ from the measured pulse shape $I(t)$.

In practice, this principle is conducted in the following procedure. First, we obtain $N(t)$ and $\{D_k(t)\}$ in a computer simulation or in the measurement using a model phantom. Then we illuminate a short pulse of light on the body tissue, and measure the received pulse shape $I(t)$. In the reconstruction process, we sample the pulse shape $I(t)$ along the time axis at n different positions. We devide the object in some layers to get the absorbance distribution in the depth-direction. The number n corresponds to the number of these layers. In this way, we can have the same number of simultaneous equations as the number of unknowns. By solving the linear simultaneous equations, we can obtain the set of unknowns $\{A_k\}$.

3. Computer Simulation

In order to examine the applicability of this technique to a diffuse medium, a computer simulation based on the Monte Carlo method was conducted. Fig.3 and 4 show the model of the simulation and the results, respectively.

When the variation of the absorption was small among layers, the reconstructed distribution agreed well with the given distribution. However, with large variation, the error became large particularly in deep layers.

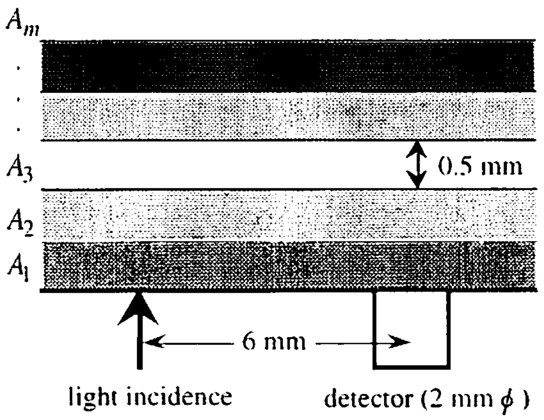
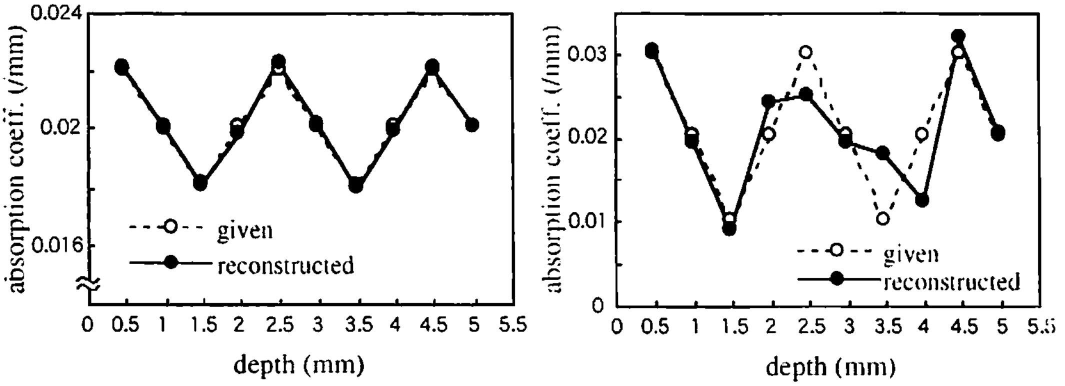


Fig. 3 Simulation model



(a) (b)

Fig. 4 Results of simulation ; (a) less absorption variance, (b) more absorption variance.

4. Conclusions

To realize the optical CT using backscattered light, a technique was newly developed to reconstruct the absorbance distribution in diffuse media. In a computer simulation, the fundamental effectiveness of this technique was verified.

The accuracy of this technique can be increased by the improvement in the linear approximation of the fundamental equation (Eq. (1)), and in the appropriate choice of sampling times of the detected pulse shape.

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