PROCEEDINGS OF ISAP '92, SAPPORO, JAPAN

SUPPRESSION OF DIFFUSE SCATTERING FOR IMAGING THROUGH DENSE RANDOM MEDIA

Koichi Shimizu, Masataka Kitama, Tatsuya Nakai
and Katsuyuki Yamamoto
Department of Bioengineering, Faculty of Engineering,
Hokkaido University, Sapporo, 060 Japan.

1. Introduction

In recent years, there has been increasing interest in imaging through dense random media. With biological tissues such as human body, the light is strongly attenuated by scattering and absorption. In the spectrum of light, a near infrared light (700-1200 nm) has relatively high transmission through biological tissues. Transillumination imaging has been attempted with biological samples. However, it has been applicable in the limited cases such as human breast. The strong scattering in tissues makes the imaging of inside structure of human body difficult.

To find a clue for the solution of this problem, the behavior of light in dense random media has been studied. Based on the analysis of the scattering, a technique has been developed to suppress the effect of scattering in the imaging through diffuse media.

2. Simulation of Diffuse Scattering

The light propagation in a dense random medium was simulated in a computer using Monte Carlo technique. The principle of simulation is illustrated in Fig.1. A flux of photons is introduced into a slab of scattering medium at the origin of the coordinate system. The photons are scattered in the direction which is determined according to the statistical distribution of a scattering pattern. The scattering pattern measured with a biological tissue[1] was used. The photon flux propagates straight until encountering a next scatterer. The flight distance D of the photon flux is given as,

$$D = -\ln(RAN) / A_s \qquad (1)$$

where RAN is the uniform random number between 0 and 1, and A_s is the scattering coefficient of the tissue. As the photon flux propagates, it is attenuated by,

$$I / I_o = \exp(-A_a D) \qquad (2)$$

where I_o and I are the light intensities before and after the propagation, and A_a is the absorption coefficient of the tissue. In the repetition of this process, some photon fluxes reach the detector placed on the other side of the slab medium, and they are accumulated as a received optical signal.

The parameters such as A_s and A_a used in the simulation were those of biological tissues reported as measured values.[2-4]

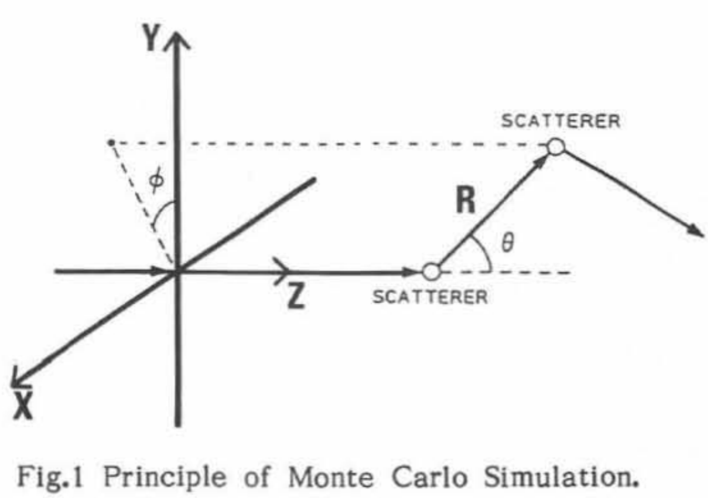

Fig.1 Principle of Monte Carlo Simulation.

3. Principle of Scattering Suppression

Fig.2 shows some loci of the photon fluxes obtained in the simulation. Photon fluxes were introduced at the origin (arrow), and propagates in the medium colliding against scatterers one after another. Based on these simulation analyses, the followings were found.

When a beam of light illuminates a diffuse object, some photon fluxes propagate closely along the optical axis. We call this as "near-axis scattered light".[5] This is due to the strong forward-scattering characteristics of the scattering pattern used which came from the measurement with biological tissues.[1]

If many loci of the photon fluxes are superimposed, the distribution of light in the medium is obtained. Fig.3 schematically illustrates the distributions of light received by two detectors separated by a short distance. As can be seen, the diffusely scattered light received in the two detectors had propagated through the similar area in the medium.

These two facts suggested a possibility to suppress the diffusely scattered light. The on-axis detector (#1) receives more near-axis scattered light than off-axis detector (#2). The diffusely scattered light received by each detector is almost the same. Therefore, by subtracting the output of the detector #2 from that of the detector #1, the scattered component is reduced and the near-axis component is relatively enhanced.

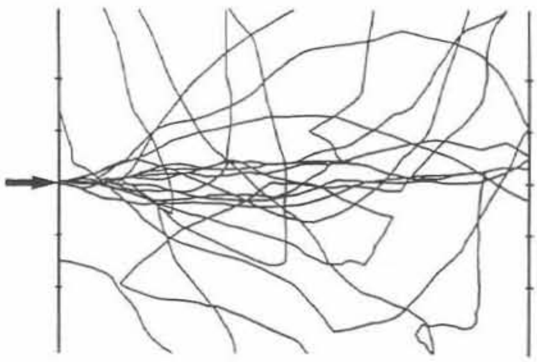

Fig.2 Loci of photon fluxes in scattering medium.

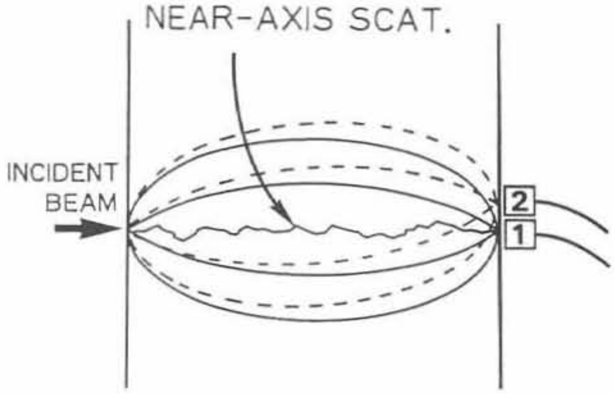

Fig.3 Distributions of light received by on- and off-axis detectors.

4. Imaging through Diffuse Media

In order to examine the reasonability of the simulation and the feasibility of the above principle, the following experiments were conducted.

Fig.4 illustrates the experiment. An image of the knife edge immersed in a scattering medium was obtained, and the spatial resolution was analyzed. As the scattering medium, whole milk was diluted with water. The milk solution was contained in a plexiglass cell with 50 mm inner-wall distance. A knife edge was immersed in the center, or 25 mm from the wall. A beam of laser light (YAG, 1064 nm wavelength) illuminates the cell from one side, and a detector unit was placed on the other side.

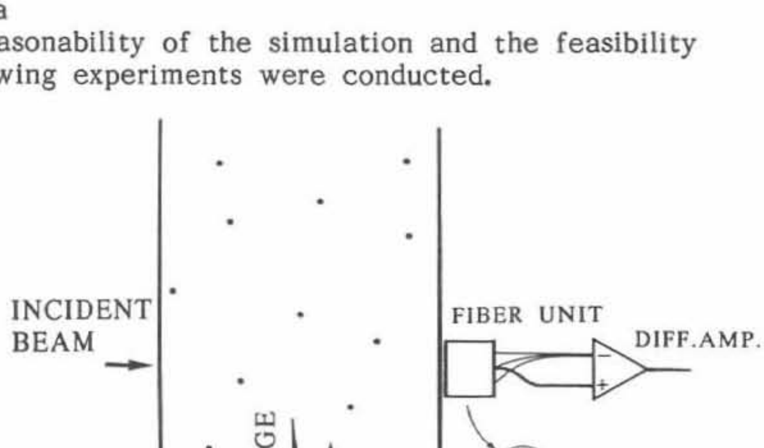

Fig.4 Measurement with near-axis technique.

The detector unit holds six optical fibers equally spaced along the concentric circle of 5 mm radius. The unit holds a bundle of six fibers in its center, as well. The optical signals carried by the two sets of fibers are fed to a differential amplifier through two photodiodes. The receiving angle of each fiber is restricted within 3 degrees.

For the comparison, similar experiments were conducted with a simple collimation technique. Fig.5 illustrates the experiment. It is the same as Fig.4 except for the receiving optical setup. With a field stop (2 mm dia.), a lens (150 mm f.l.) and a pinhole (1 mm dia.), the uncollimated scattered light is suppressed more than the light collimated with the incident beam.

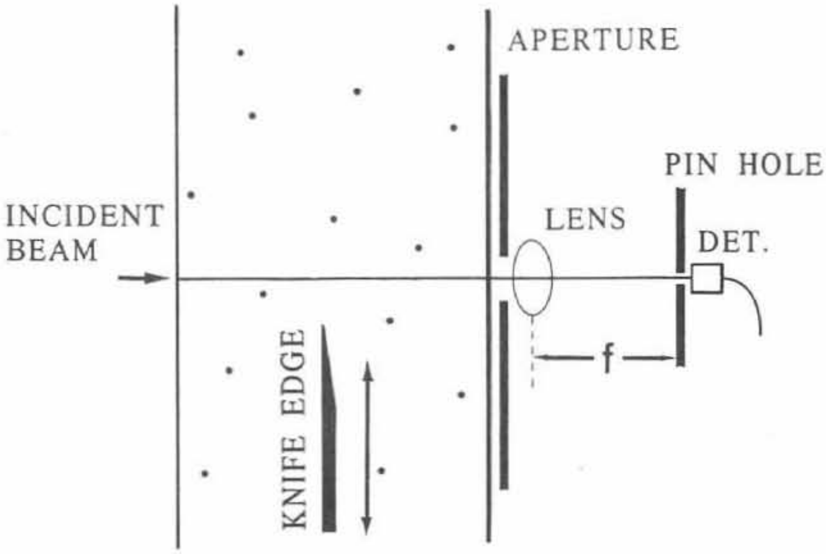

Fig.5 Measurement with collimation technique.

Fig.6 shows the result of the measurement. Fig.6(a) shows the images of the knife edge obtained with the collimation technique. As the degree of scattering increased, the resolution becomes apparently poor. Fig.6(b) shows the same images with the principle proposed above. The resolution was maintained in the same level due to the scattering suppression.

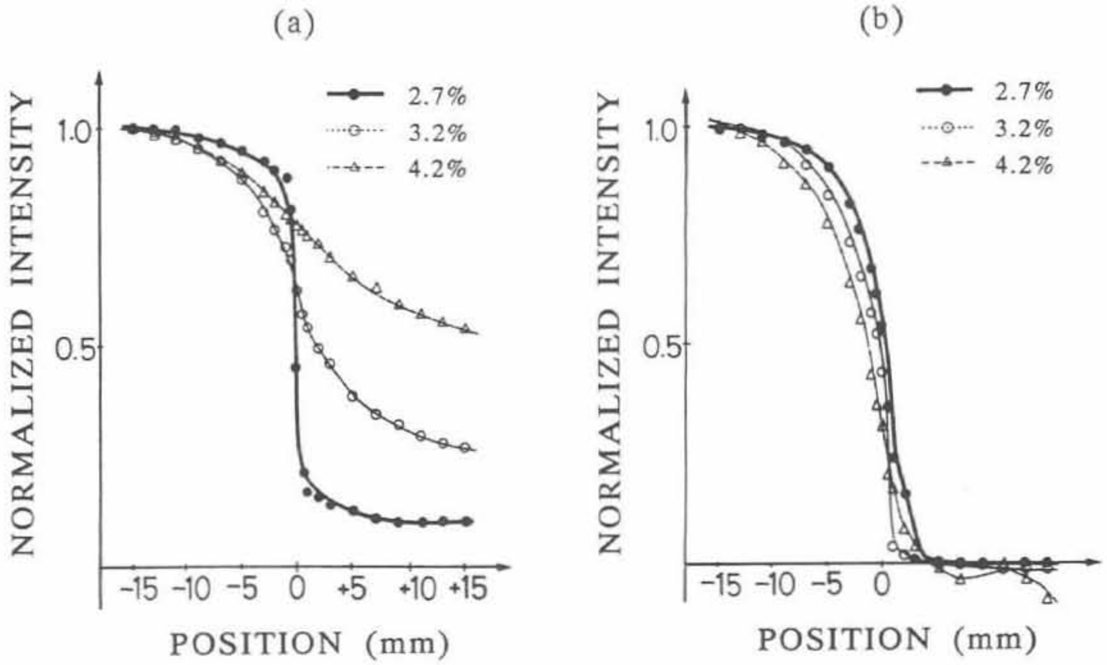

Fig.6 Imaging of knife edge through milk solution
(a) collimation technique,
(b) near-axis scattering technique.

Finally, this technique was applied to biological tissue. White meat of chicken was used as a scattering medium. Other conditions of the experiment were the same as above. Fig.7 shows the result of the measurement. Compared with the collimated case (Fig.7(a)), the diffuse scattering was suppressed effectively with the proposed technique (Fig.7(b)).

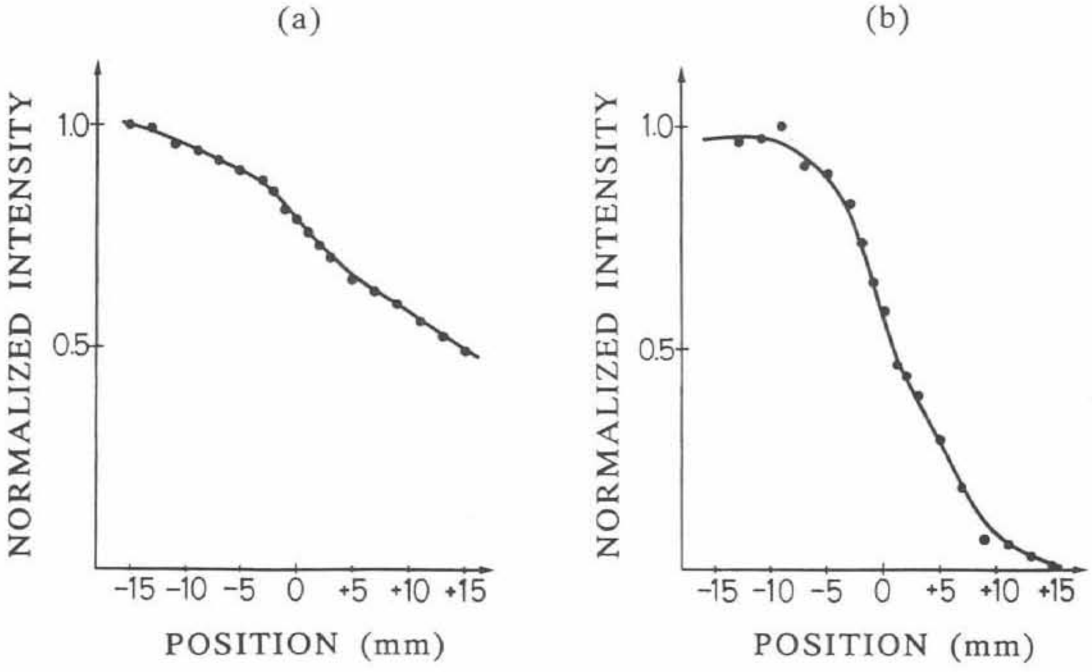

Fig.7 Imaging of knife edge through biological tissue
(a) collimation technique,
(b) near-axis scattering technique.

5. Conclusions

For the imaging through dense random media, we have studied the light propagation in the diffuse medium such as biological tissues. In a computer simulation, the behavior of light in the medium was analyzed. Based on the results of the analysis, a technique was proposed to suppress the diffuse scattering. In experiments, the effectiveness of the technique was verified, and its applicability to biological tissue was confirmed.

This technique seems to have promising potential to visualize the internal structure of animal body using light. It may be able to contribute to the realization of an optical CT.[6]

The authors wish to thank Professor Mamoru Tamura, Hokkaido University, and Professor Tomohisa Mikami, Hokkaido Tokai University, for their valuable cooperation. This research was supported in part by the Ministry of Education, Science and Culture (03805032) and Casio Science Promotion Foundation.

References

[1] P. van der Zee, et al., Adv. Exp. Med. Biol., 222, 191 (1987).
[2] J.L. Karagiannes, et al., Appl. Opt., 28, 2311 (1989).
[3] R. Marchesini, et al., Appl. Opt., 28, 2318 (1989).
[4] P. Parsa, et al., Appl. Opt., 28, 2325 (1989).
[5] T. Nakai, et al., IEICE Tech. Rep. MBE90-70, 35 (1990).
[6] K. Shimizu, et al., Med. Biol. Eng. Comp., 29 suppl., 604 (1991).