Depth Estimation of an Absorbent Embedded in a Dense Medium Using Diffused Wave Reflectometry

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Abstract. The purpose of this research is to propose a new and simple method in measuring the depth of an absorbent embedded in a dense scattering medium by using a diffused wave reflectometry. The estimation of the depth of the absorbent is based on the assumption that the total intensity over the backscattering plane equals to the probability that the intensity profile is formed by the contribution of the waves with the path-length shorter than a certain maximum path-length. To confirm the principle, the Monte Carlo simulations and experiments are repeated for the absorbents with various depths and shapes and the various positions of the beam incidence. Finally, we demonstrate the validity of the proposed principle and the possibility to apply the new method to the surface profiling of the absorbent, i.e. the diffused wave topography.

1 Introduction

The techniques based on the light scattering have been playing an important role in the optical diagnosis and therapy for human tissues. The analysis of the tissue structure with thickness over a few millimeters is still an open problem. The technique for the such the thickness of tissues will be powerful for diagnoses of a breast cancer and a tumor near the skin layer, the analysis of the blood flow dynamics near the surface layer of the brain and so on.

For such the thick tissue, the diffused wave is dominant in the light scattering. The purpose of the research is to propose the new and simple method based on the diffused wave reflectometry to estimate the depth of the absorbent embedded in the dense scattering medium. The proposed method is based on the relation between the probability density function of the optical path-length and the total intensity integrated spatially over the backscattering plane. The principle of the depth estimation is successfully confirmed by Monte Carlo simulations and experiments and applied to the surface-profiling method of the absorbent.

2 Principle of Depth Estimation

The absorbent restricts the contribution of scattered waves to the total backscattered intensity within those with the path-length shorter than the certain maximum path-length. Assuming that the total intensity over the backscattering plane equals to the probability that the waves with the path-length shorter than the maximum path-length L contribute to the formation of the intensity profile, the assumption is formularized as

$$P(L)=\int_0^L p(s)ds \Big/ \int_0^\infty p(s)ds = \int_\Sigma I_a\, dS \Big/ \int_\Sigma I_0\, dS \qquad (1)$$

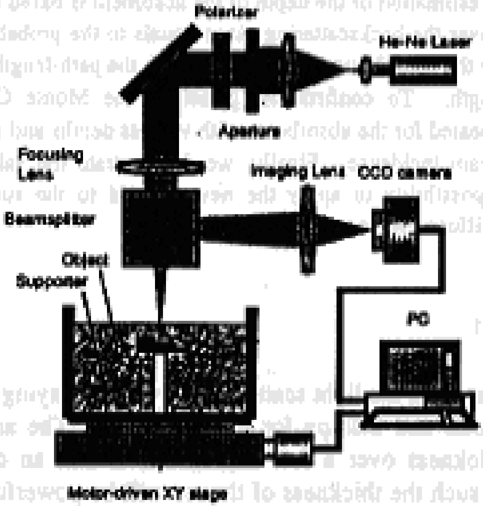


Fig.1. Experimental setup. The focused beam emerging from the He-Ne laser with the 633nm-wavelength is incident to the dense scattering medium which is composed from the 1%-suspension of the 460nm-polystrene particles. The black- and mat-painted absorbent is supported by a thin rod in the scattering medium.

where p(s) is a probability density function of the optical path-length when the absorbent does not exist, I_a and I_0 the intensity profiles produced from the media with and without the absorbent, respectively, and Σ the area over the backscattering plane. This principle corresponds to renormalizing the variation in p(s) due to the restriction of the scattered waves by the absorbent to the maximum path-length L. In Eq.(1), the probability density function p(s) can be obtained by the Monte Carlo simulation or as the analytical solution of a diffusion equation of photons in advance and Ia and I0 are observable values in the experiment.

To estimate the depth from the backscattering plane to the surface of the absorbent, it is assumed that the maximum path-length L is directly proportional to the depth d of the absorbent and defined by

$$L = \alpha d\ . \qquad (2)$$

The constant α is optimized by Monte Carlo simulations in such the way that the squared error between the estimated and the give depth of absorbent is minimized for various depths of the absorbent. For 1%-suspension of 460nm-polystrene latex particles, α=3 was obtained as the optimum value.

3 Experiment Setup

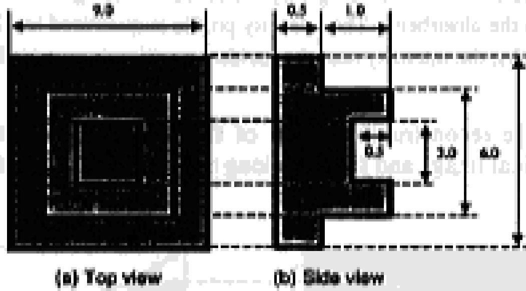
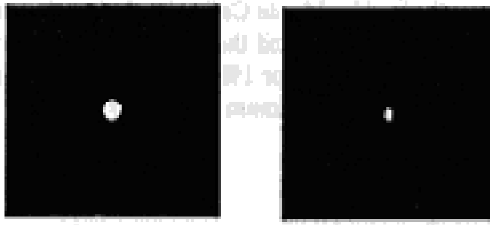


Fig.2. (a) Top view and (b) side view of the absorbent used in the experiment, which is painted black and mat.

The experimental setup is schematically shown in Fig.1. The laser light with the wavelength of 633nm is focused to the backscattering plane. The absorbent shown in Fig.2 is supported by the thin rod in the 1%-suspension of 460nm-polystrene latex particles that the 5cm×5cm×1cm-vessel is filled with. The backscattered intensity profile is formed by the light waves traveling along the long trajectories inside the medium, and imagined in a CCD plane of the digital camera with 1/5 magnitude. The digital image is fed into the microcomputer and integrated spatially over the backscattering plane. The incident position of the laser beam is two-dimensionally moved by a motor-driven XY stage.

4 Experimental Results

Figures 3 (a) and (b) show the intensity profiles of backscattered light by the latex particle suspensions without and with the absorbent, respectively. The comparison between the figures shows that both the peak and extension of the profile decrease due to the ray restriction by the absorbent. As is mentioned above, the variation of the probability density function of the path-length due to the absorbent is reflected to the intensity profile in the backscattered plane.



(a) (b)

Fig.3. Intensity profiles of backscattered light by the dense scattering medium (a) without the absorbent and (b) with the absorbent. The intensity profile is quantized to 12 bit gray scales. To show the photographs, the intensity near the incident position is saturated.

Figure 4 shows the reconstruction result of the absorbent shown in Fig.2, in which the topographical image and the line along the horizontal axis at the center of

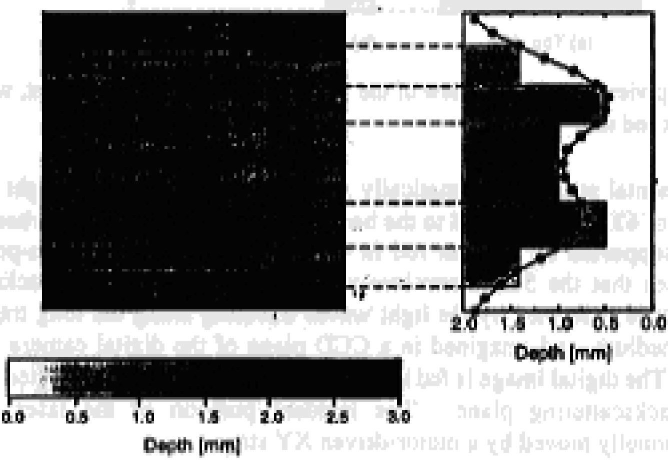


Fig.4. Reconstructed absorbent using the proposed method based on the diffused wave topography. The left and right figures show the two-dimensional surface profile of the absorbent and the line scanned along the vertical axis at the center of the horizontal axis, respectively.

the vertical axis. The gray scale indicates the distance from the backscattering plane to the surface of the absorbent, in which the depth increases from the white to the black. It is shown that the surface profile is successfully reconstructed by the proposed method though the edge is blurred.

5 Conclusion

In this study, the depth of the absorbent embedded in the dense medium was successfully estimated by the diffused wave reflectometry. Although the new principle of the measurement is quite simple, the reconstruction of the topographical image of the absorbent shape could be attained.

Acknowledgements

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