EXPERIMENTAL STUDY ON SPECKLE PATTERNS OF LASER LIGHT IN THE FAR RANGE

Yoshihiko TOYOSHIMA†, Takashi INABA† and Tadashi TAKANO*
† Department of Electronics Engineering, The University of Tokyo
7-3-1 Hongo, Bunkyo-ku, Tokyo 113-8656 Japan
* Japan Aerospace Exploration Agency, The Institute of Space and Astronautical Science
3-1-1 Yoshinodai, Sagamihara-shi, Kanagawa 229-8510 Japan
Email: arpa@radionet.isas.jaxa.jp

1.Introduction

Using the light-wave in a radar or a wireless LAN of a diffused type [1], the light is scattered on the material and propagates to the receiver. Therefore, it is most important to understand the scattering phenomena for system design. The scattered pattern from several materials have been measured. Particularly, it was shown that acrylic plastic has Lambertian pattern due to strong internal scattering and a reflection pattern from the surface[2].

Speckles which are caused by a rough surface and appear in Lambertian pattern, are another factor to affect the receiving power level. The speckle phenomena have been studied for the measurement of material surfaces mostly in the near region from a scatterer, e.g. within several tens centimeters[3]. Speckle patterns for several materials were measured in the far region for the purpose of laser measurement or communications. The data were analyzed on the basis of integral calculation of auto-correlation function which is conventionally called the speckle contrast (SC). The speckle fluctuation parameter (SFP) which is defined by the maximum and minimum values of the fields in a speckle pattern, was proposed to express the speckle phenomena in the easier way[4]. They showed the correspondence between two parameters.

In this research, the distance from a scatterer to an observer (R), the laser beam size and the number of lasers are changed to investigate the effects to the speckle patterns on the basis of the FFT. We have introduced a digital recorder, and carried out the spatial-spectral analysis of the speckle pattern, This paper describes the experimental results.

2. Configuration of the experiment system

The experiment system is shown in Fig.1. The light from the a laser hits a scattering object. In the scattered light, A photo diode with a 1mm diameter pin hole is scanned vertically to the scatterer

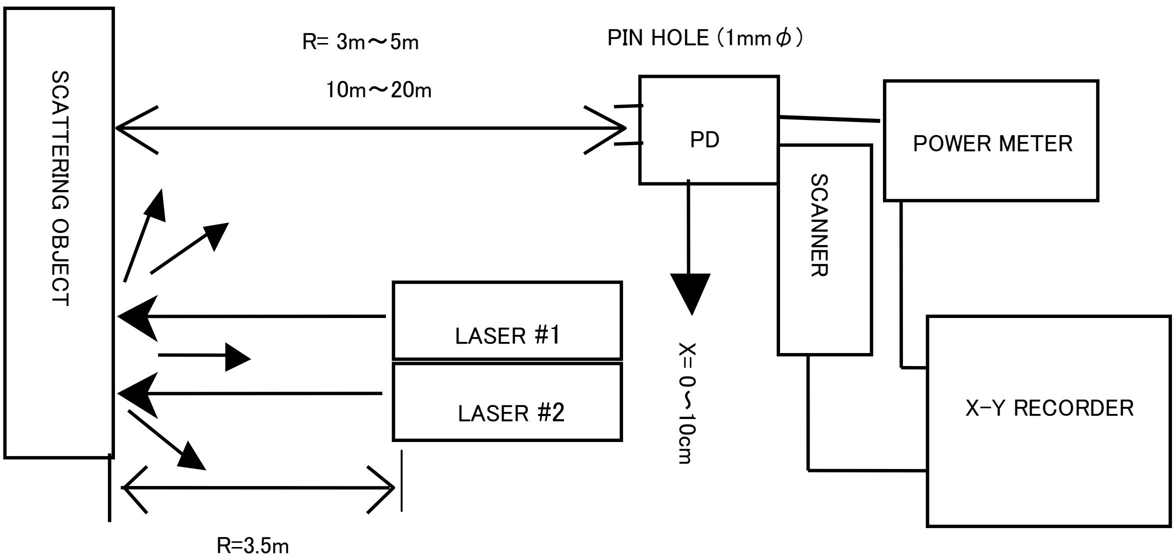


Fig. 1 Experiment system.

ISBN: 4-88552-207-2 C3055©IEICE

direction to obtain speckle patterns. The data is recorded in the X-Y recorder, and can be processed for Fourier analysis with a digital recorder.

The lasers are YAG-type whose specifications are listed in Table 1. Due to the visible green light, the experiment is carried out more easily and less dangerous than infrared lights. Depending on an experiment purpose, one or two identical lasers were used. And the laser beam was expanded using a lens at the output of the laser in order to investigate the dependence on the beam size.

For R=10～20m, the received light becomes so weak that the whole experiment system is enclosed in a dark tunnel.

Table.1 Specifications of YAG laser

Wave length	532nm
CW Output	25mW
Transverse mode	TEM_{00}
Beam angle (full width)	2mrad
Beam radius ($1/e^2$)	0.36mm
Coherence length	10mm

3. Speckle pattern and spatial spectrum versus distance

The scattering object is white paper which is usually used for a copy machine. At first a single laser was used as a light source in the configuration in Fig.1. The data at the distance R=3.0m is shown by a thinner curve in Fig.2 (a).

The speckle contrast SC is expressed by[3]

$$SC = \frac{(<I^2> - <I>^2)^{1/2}}{<I>} \qquad (1)$$

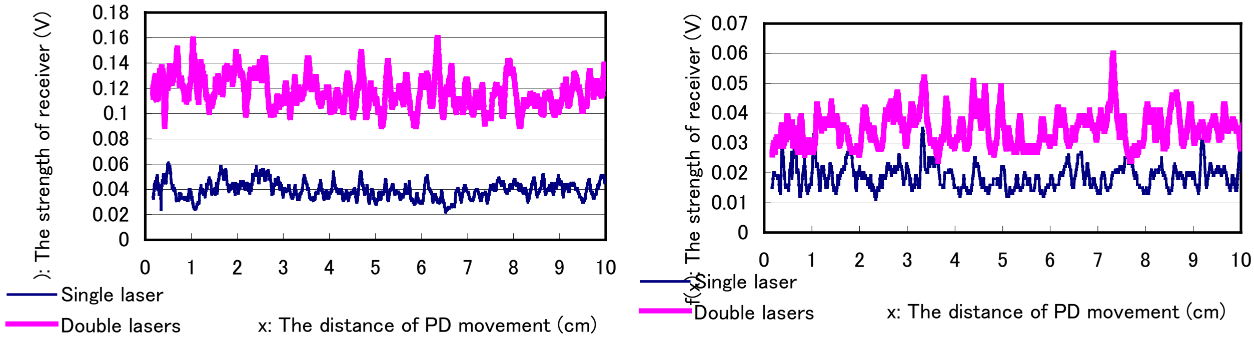
where I is the amplitude of the speckle pattern, and <*> represents the averaged value.
The speckle fluctuation parameter SFP is defined by

$$SFP = \frac{I_{max} - I_{min}}{I_{max} + I_{min}} \qquad (2)$$

where I_{max} and I_{min} represent the maximum and minimum values of I, respectively.
In this case, SC is calculated to be 0.17, and SFP to be 0.49, respectively.

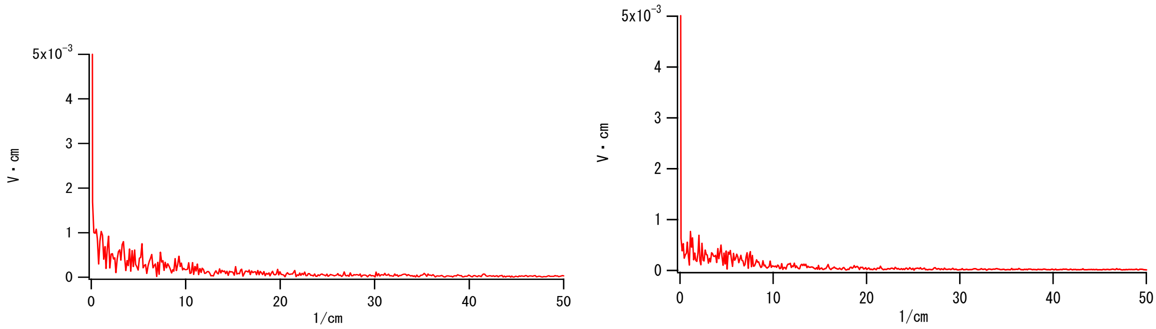
Then, R is changed, and the data at R=5.0m is shown by a thinner curve in Fig.2 (b). The average power level at R=5.0m is 0.04 which is 0.36 times that at R=3.0m, as is coincident with the scattering theory. It is apparent that the speckle pattern is more ragged than in Fig.2 (a). The SC and SFP in this case are 0.21 and 0.52, respectively, which are both much larger than those for Fig.2(a). This fact shows the speckle patterns do not change in the angle domain, but become more ragged with larger R.

The data were stored in the digital recorder, and processed for Fourier analysis in the spatial frequency or angle domain where the angle is approximately equal to x/R. The lower cut-off frequency due to the limit of x is 0.1 [1/cm] and the higher cut-off frequency due to the pin hole size of PD is 10 [1/cm]. The obtained spatial spectra at R=3.0m and 5.0m are shown in Fig.3 (a) and (b), respectively. The shapes are similar, if the horizontal axis for R=5.0m is extended by the ratio of 5/3.



(a) R= 3.0 m (b) R=5.0m

Fig.2 Speckle pattern from paper.



(a) R=3.0m (b) R=5.0m

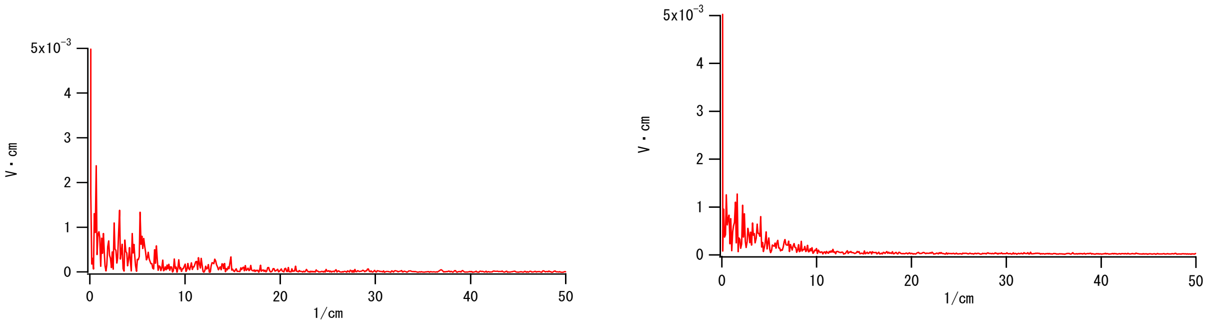
Fig.3 Spatial spectrum of speckle pattern from paper (single laser).

4. Dependence on the laser number and beam size

An identical laser was added to form the same configuration as Fig.1. The data at R=3.0m is shown by a thicker curve in Fig.2 (a). The average power level is almost doubled from the single laser case, but the variation is not doubled. Actually, SC and SFP are 0.11 and 0.24, respectively, which are both much smaller than those in the single laser case. This fact shows that a plural laser system is advantageous to reduce the speckle pattern effects. At R=5.0m, the same can be said in Fig.2 (b). The SC and SFP are 0.17 and 0.42, respectively.

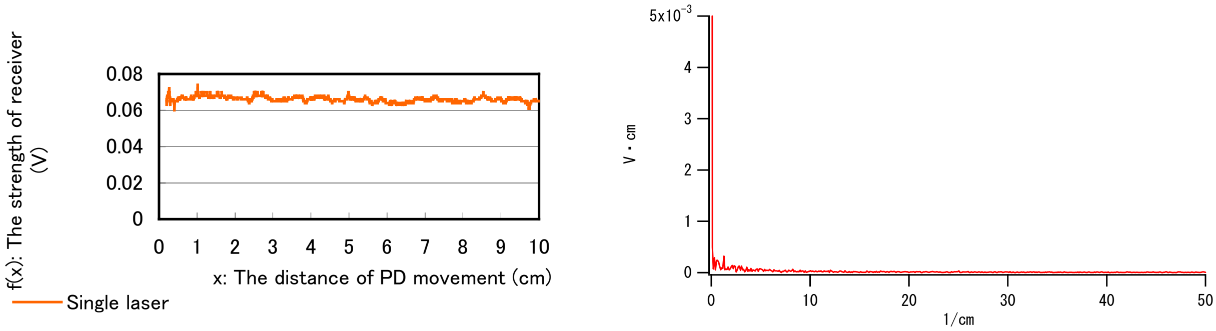
The spatial spectra are calculated. The result for R=3.0m is shown in Fig.4. The spectrum energy is more biased to the low frequency than that of the single laser case. The same can be said for R=5.0, comparing with Fig.3 (b).

The laser beam to a scattering object was expanded from 0.7mm to 30mm by a lens. The measured speckle pattern at R=3.0m is shown in Fig.5. The average power level is 0.066 which is slightly larger than the narrow beam case. The variation of the level is much less than the narrow beam case. Actually, SC and SFP are 0.05 and 0.47, respectively. The derived spatial spectrum is concentrated in the low frequency as shown in Fig. 5 (b).



(a) R= 3.0m (b) R=5.0m

Fig.4. Spatial spectrum of speckle pattern with double lasers (paper, R=3.0m).



(a) Speckle pattern (b) Spatial spectrum

Fig.5. Speckle pattern Characteristics with an expanded beam (paper, R=3.0m).

5. Conclusions

(1) The correspondence between a speckle pattern and the spatial spectrum is shown for several distances from the scattering surface to the observation point.

(2) Speckle patterns become more ragged, and the angles subtended by the pattern do not change for larger distances.

(3) The speckle contrast in the case of double lasers is $1/\sqrt{2}$ times that of the single laser case, though the total averaged power level is two times.

(4) The speckle contrast is shown to be inversely proportional to the diameter of the laser beam.

Acknowledgement

This research is partially supported by the 21st Century COE in Electrical Engineering and Electronics, The University of Tokyo.

References

[1] J.R. Barry, “Wireless Infrared Communications” ,Kluwer Academic Pub., 1994.

[2] T.Ninomiya, T.Toda and T.Takano, "Lightwave Reflection and Scattering on Various Materials", Proceedings of ISAP'2000. pp.1469-1472, Fukuoka, August 2000.

[3] J.C.Dainty, A.E.Ennos, M.Francon, J.W.Goodman, T.S.McKechnie, G.Parry, “Laser Speckle and Related Phenomena”, Springer-Verlag Berlin Heidelberg New York 1975.

[4] H.Toba and T.Takano, “Mitigation of Speckle by Spatial Conbining of Plural Laser Powers”, Proceedings the 2002 IEICE General Conference, B-10-105, 2002.

[5] Y.Toyoshima and T.Takano, “Speckle Effect of Scattering Light from Material having Reflection of Mirror Face”, Proceedings the 2002 IEICE Society Conference, B-10-105, 2002.