Study of Speckle Phenomena - Dependence on an Irradiated Area Size and Scattering Materials and the Effcts in a Laser Radar

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1 Introduction

Using light-wave in a laser radar or a wireless LAN of diffused type, speckle phenomena can cause error of received signals. Speckle is caused by the interference of randomly scattered lights and appears as a random pattern. In the case a receiver moves into a dark point of the pattern, the received power decreases significantly.[1]

Speckle effects on a received power depend on the ratio of the spatial size of a speckle pattern to the receiving aperture diameter. If a receiving aperture is much larger than the speckle size, speckle pattern is averaged and the received power does not fluctuate much by speckle phenomena. In a assumption of sufficiently random scattering, the average size of speckle pattern was theoretically showed to be equal to $\lambda R_{ob}/D$. (λ: wavelength, R_{ob}: distance between a scattering object and a receiver, D: illumination area diameter) [2] And a dependence of speckle effects on a receiving aperture diameter was also analyzed based on the theory. [3]

In this research, we experimentally investigate the dependence of speckle phenomena on an illumination area, a receiving aperture diameter and a scattering material. We also analyze a fluctuation of a received power in a pulse laser. Measured speckle sizes are larger than the theoretical values with large dispersion. Especially, speckle paterns with spatially large periodicity which does not depend much on an illumination area is serious problem in a far range laser radar system. We also show that speckle causes a large scale fluctuation of received energy in a laser radar.

2 Configuration of experimental system

A configuration of experimental system is shown in Fig.1. A scattering object which is wood plate, paper or sandpaper is irradiated by CW or pulse laser. The laser is a YAG type with wavelength of 532nm.

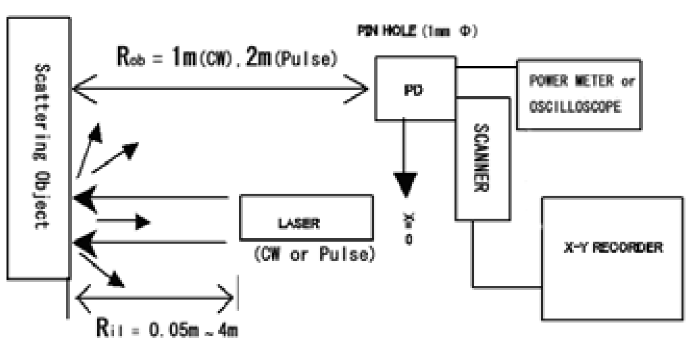

Figure 1: Configuration of Experimental System.

In a measurement of speckle pattern, we use a CW laser with the beam angle of 2mrad and the radius of 0.36mm and move a photo diode laterally to the scattering direction to measure the light intensity distribution. The illuminate area is changed by changing the distance between a laser and

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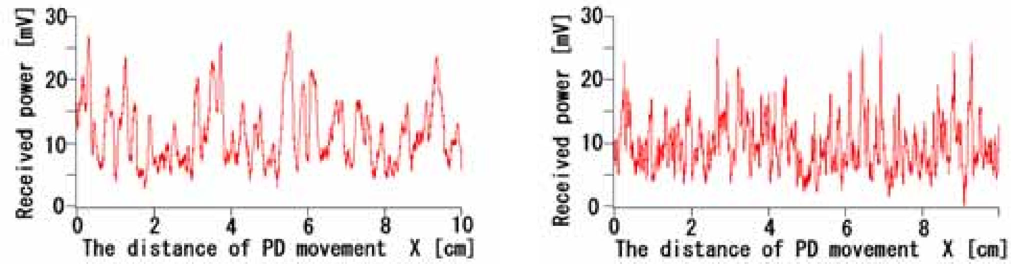
an object. In a measurement using a pulse laser with the beam angle of 0.474mrad, the radius of 0.948mm and the repetition rate of 20Hz, we observe a received waveform with an oscilloscope in a snap-shot mode. In this case, the illuminate area is changed narrowing the laser beam by a lens.

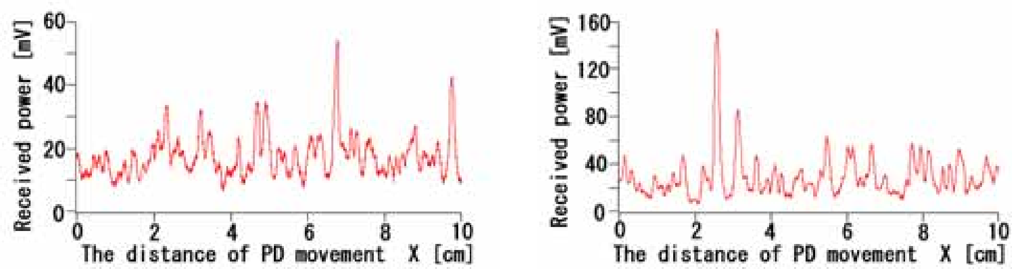
3 Dependence of speckle pattern on system parameters

Measured speckle patterns are shown in Fig.2. As the diameter D of the illuminate area increases, obviously the pattern becomes of shorter period or faster vatiation pattern. From Fig.3 in addition to Fig.2(a), a magnitude of variation depends on scattering materials but the speckle size seems not to depend on materials. A strong peak caused by specular reflection can be recognized in the case of sandpaper.



(a) D=0.8mm (b) D=2.4mm

Figure 2: Speckle pattern for various illumination diameters (planed wood plate without paint (broad leaf tree)).



(a) paper (d) sandpaper (♯80)

Figure 3: Speckle pattern for several materials (D=0.8mm).

An average speckle size is evaluated by means of the autocorrelation of patterns. Dependence of the average speckle size on illumination area is shown in Fig.4. The axis shows the normalized inverse D. The dependence of speckle size on scattering materials is not clear. The theoretical speckle size $\lambda R_{ob}/D$ shows the minimum values of speckle size in reality.

We evaluate dispersion of the speckle size by dividing a pattern and calculating speckle size in each partial patterns. Dependence of a standard diviation of a speckle size on D is shown in Fig.5.

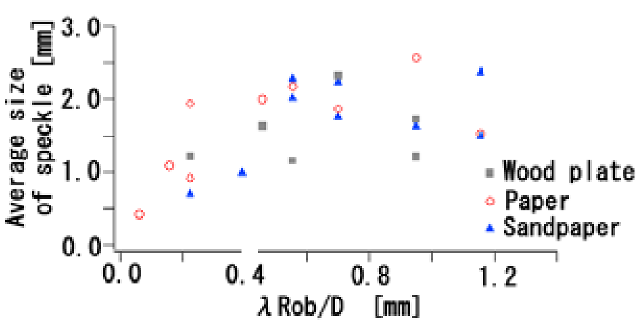


Figure 4: Average speckle size dependence on illumination diameter D.

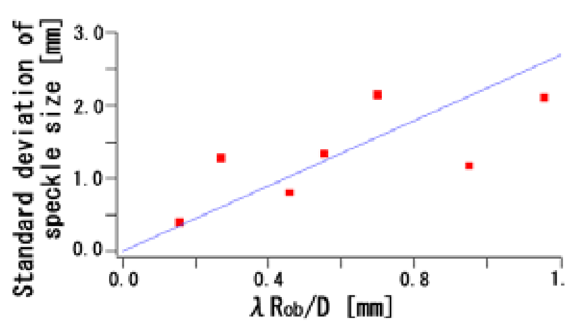


Figure 5: Dependence of a standard deviation of a speckle size on illumination diameter D.

The speckle size has a large standard deviation and is as large as twice average size at maximum.

4 Evaluation in terms of speckle contrast

We evaluate speckle effects in the case of larger receiving aperture by processing measured pattern using averageing. In the case of a receiving aperture diameter d_r, the average light intensity in a region from $x - d_r/2$ to $x + d_r/2$ is identified as the received energy at the point x.

Speckle Contrast (SC) is used to evaluate the magnitude of speckle phenomena. SC is expressed by $SC = (< I^2 > - < I >^2)^{\frac{1}{2}} / < I >$ where I is the amplitude of the speckle pattern, and $< * >$ represents the averaged value. Without speckles, SC=0.

The SC is calculated for the whole data which were experimentally obtained. Dependence of SC on receiving aperture diameter is shown in Fig.6. As aperture diameter is increased, speckle effects are suppressed by averaging of pattern in the aperture. In the case of sandpaper, SC decreases drastically with an increase of aperture diameter, On the other hand, in the case of wood plate or paper, the decrease of SC is low while d_r is from 5mm to 15mm. And, the property is prominent in the case of wood plate.

Spatially large periodicity which is above 20mm and appear in the speckle pattern from wood plate (Fig.2(a)) causes the low decrease rate of SC. The caliculated pattern in the case of $d_r = 5mm$ (wood plate, D=0.8mm) is shown in Fig.7. In the case of a diameter smaller than 5mm, patterns with shorter periods are averaged so that SC decreases in the same way regardless of materials. On the other hand, for the diameter from 5mm to 20mm, the aperture is still smaller than the large pattern cycle, and, thereby, an averaging effect of pattern is insufficient.

A periodicity in a scattering surface can be assumed to cause large periodicity of the pattern. A scattering surface of wood plate or paper composed of fibers can have periodicity to some extent. On the other hand, a sandpaper having more randam surface does not cause the periodic pattern.

From Fig.2(a),(b), we can assume that the large cycle doesn't much depend on the illumination area D. The pattern that doesn't depend on D can be serious problem in a far range laser radar system because the size increases in propotion to the target distance.

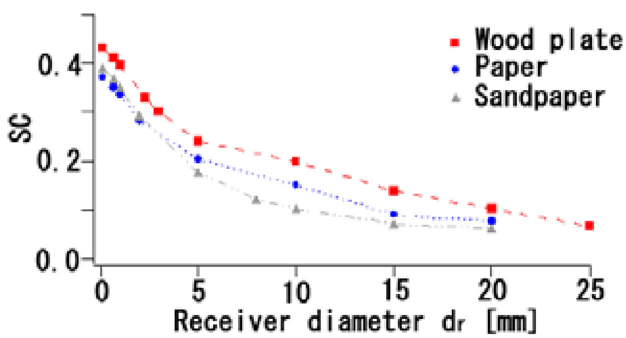


Figure 6: SC dependence on receiving diameter.(D=0.8mm)

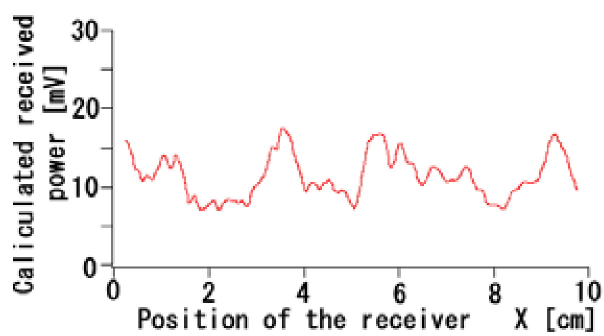


Figure 7: caliculated pattern in the case of $d_r = 5mm$. (wood plate, D=0.8mm)

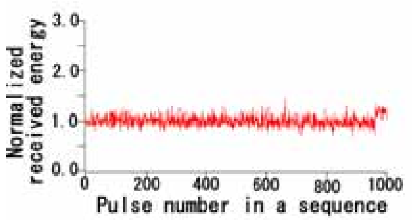
5 Fluctuation of the received energy in a laser radar

The scattered energy from paper and sandpaper in a laser radar was measured for the continuation of snap-shpts of pulses. The results are shown in Fig.8.

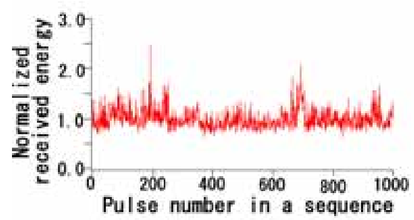
In the case D=0.1mm, received energy fluctuates in a large time scale of 20[s]. In the case D is larger than 0.5mm, received energy fluctuates in a small time scale as 1[s] or below. The changes of speckle pattern is caused by variations of light inteisity distribution in the transmitted beam or thermal changes oi scattering objects. In the case of D=0.1mm, the beam diameter is very small and such variations do not affect the spekcle pattern much, Therefore, the pattern changes in a large time scale.

In the case of D=0.5mm, received energy fluctuates in a wide range of 0.5 to 2.5 of average. In the case of D=2mm, the variation is reduced and become close to the variation of transmitted energy. Theoretical speckle size at the receiver position in the case of D=0.5mm and 2mm is caliculated as 1mm and 0.1mm, respectively. In the case of D=2mm, speckle effects are supressed by the averaging of pattern in a receiving aperture.

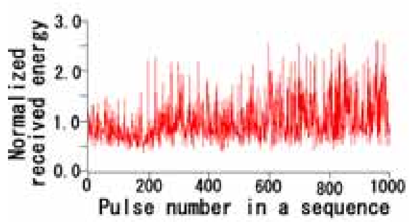
Fluctuation of the received energy in the case of sandpaper is shown in Fig.9. The received energy fluctuates in a wider range of 0.2 to 2.6 than that with case of paper.



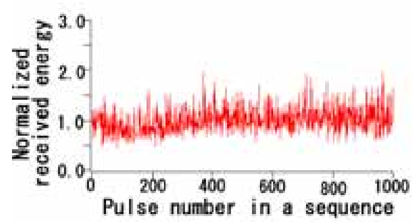
(a) transmitted energy



(b) D=0.1mm

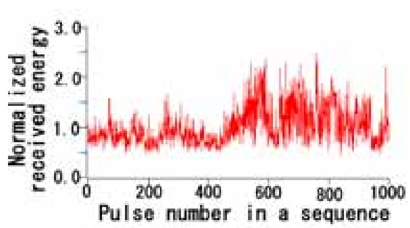


(c) D=0.5mm

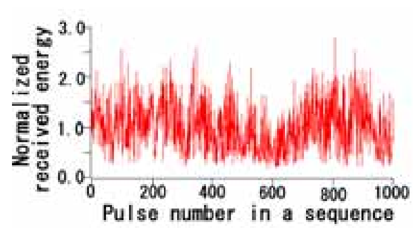


(d) D=2mm

Figure 8: Fluctuation of a transmitted signal and a received signal from paper in a laser radar.



(a) D=0.1mm



(b) D=0.5mm

Figure 9: Fluctuation of a received signal from sandpaper in a laser radar.

6 Conclusion

1. It is shown experimentally that average speckle size is larger than the theoretical value $\lambda R_{ob}/D$.
2. Speckle size has a large dispersion and becomes twice as large as average size in some cases.
3. Spatially large periodicity which doesn't depend much on a illumination area appears in speckle pattern from wood plate. Such pattern can be serious problem in a far range laser radar system because the fluctuation can not be eliminated by averaging.
4. Received Energy of laser radar fluctuates drastically in a time domain due to speckle effects.

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