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RSRE
MEMORANDUM No. 4339

ROYAL SIGNALS & RADAR ESTABLISHMENT

REFLECTIVITY ESTIMATES FOR LASER RANGEFINDER TARGETS AT 1.06 AND 2.06 MICRONS WAVELENGTH

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PROCUREMENT EXECUTIVE,
MINISTRY OF DEFENCE,
RSRE MALVERN,
WORCS.

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SUMMARY

Measurements were made of the reflectivities of some 'typical' laser rangefinder target materials by two methods and at two wavelengths. The first method involved the measurement of the return signal strength in laser rangefinders operating on targets in the field with allowance for the geometry of the target. The second method employed a spectrophotometer in the laboratory to find the diffuse reflectivity of material samples. Some interpretation of the results is given, including especially the differences due to the wavelengths used.

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M J P PAYNE AND H W EVANS

INTRODUCTION

The design of military laser systems acting on non-cooperating remote targets requires some knowledge of the targets' characteristics in reflecting radiation at the laser wavelength. Some information is available for the commonly employed neodymium:YAG output wavelength of 1.064 μm. Lasers based on holmium-doped YLF crystals emit at 2.064 μm wavelength and may be used in alternative, eye-safe systems. This Memorandum descibes some measurements of target reflectivity made simultaneously at both wavelengths. The reflectivity of such targets is generally to be expected to vary with the wetness, dirtiness and chemical state of the surface, of course.

RANGEFINDER EXPERIMENTS

The reflectivities of a variety of targets were measured by suitable detection of the received signal strength in a pair of laser rangefinders (LRFs) operating at wavelengths of 1.064 μm and 2.064 μm respectively. Both rangefinders were hand-held devices constructed by RSRE. The 1.06 μm LRF employed a passively Q-switched neodymium-doped YAG laser and emitted pulses of energy about 6 mJ and duration about 10 ns. The receiver aperture was 5 cm with a silicon avalanche detector. The 2.06 μm LRF used a holmium-doped YLF laser with an electro-optic Q-switch. The output pulses were of energy about 10 mJ and pulse length about 12 ns. The detector was a pin diode of InGaAs and the receiver aperture was 5 cm. The beam divergence in each case was about 1 mrad. Both LRFs incorporated a 'swept gain' facility in the receiver circuitry in the usual way but the the gain variation was set differently in the two cases to optimise for the differences between both the receiver component properties and the atmospheric backscattering properties at the two wavelengths.

The two rangefinders were mounted side by side, with their laser beam directions accurately parallel (within 0.2 milliradian). The received optical power for each equipment could be attenuated by means of an aperture of variable diameter mounted coaxially with the receiver lens. Range measurements were made on selected targets, all at approximately the same range, and the attenuating aperture was varied until correct operation was achieved on about 50% of occasions. The electronic signal amplitude presented to the threshold detector in the receiver of each rangefinder was then of an approximately constant value; the diameter of the attenuating aperture was a measure of the strength of the received optical signal. The constancy of receiver sensitivity over the central portion of the receiver apertures (as used in these experiments) had been confirmed previously.

The reflectivity of red brick was assumed to be known from laboratory measurements (see Appendix). The reflectivities of the other targets could then be calculated, with allowance for:

i range differences

ii amplifier gain differences (swept gain)

iii target aspect angle.

THEORY

The received signal amplitude is proportional to

$$S = r\, A^2\, G \cos \phi_a / R^2 \qquad (1)$$

where r = target diffuse reflectivity, assumed Lambertian

ϕ_a = target effective aspect angle

A = diameter of receiver aperture

R = target range

G = receiver amplifier gain

For the holmium LRF, G is approximately constant for ranges greater than about 1000 m. For the neodymium LRF G increases by about 1 dB per microsecond of ranging interval at ranges of about 1300 m. Thus for the neodymium LRF, G is taken as

$$G \sim 1.12^{\,((R/\text{metre}) - 1000)/150} \qquad (2)$$

For plane reflecting surfaces such as walls, the target aspect angle is the angle between the incident laser beam and the normal to the surface. For more or less randomly arranged individual reflecting surfaces, such as the leaves of a tree, all aspect angles are present simultaneously in the proportion of sinϕ.cosϕ, $0 \leq \phi \leq 90°$. The effective aspect angle is then ϕ_a with

$$\cos \phi_a = \overline{\cos \phi} = \int_0^{\pi/2} \cos^2 \phi .\, \sin \phi .\, d\phi \Big/ \int_0^{\pi/2} \cos \phi .\, \sin \phi .\, d\phi = 2/3 \qquad (3)$$

For reflection from a grass field, the reflecting surfaces are randomly oriented about a vertical axis, so that

$$\cos \phi_a = \int_0^{\pi/2} \cos^2 \phi . \, d\phi \Big/ \int_0^{\pi/2} \cos \phi . \, d\phi = \pi/4 \qquad (4)$$

From the (brick) target of known reflectivity and the appropriate critical value of A, the value of a 'standard' value of S (S_0) is found for each LRF from eq. (1). S_0 is a parameter representing the sensitivity of the rangefinder. The reflectivity of other targets is then determined by

$$r = S_0 R^2 / A^2 G \cos \phi_a \qquad (5)$$

RESULTS

The estimates of target material reflectivity are presented in Table 1. The values given are those derived for the Lambertian reflectivity for normally incident and reflected radiation. As such, they may be compared directly with the results from laboratory measurements shown in Table A1. The target reflectivity relevant for rangefinder systems equals the tabulated Lambertian value multiplied by the given value of cos ϕ_a.

The values for red brick reflectance were chosen as standard from Table A1 as being least likely to vary from sample to sample and also because rangefinder target geometry would generally be best defined for targets of brick. Thus the measurements from target 1 were used to calculate the value of S_0 for each rangefinder, under the assumption that the Lambertian reflectivity of the house bricks equalled that of the laboratory sample.

The reproducibility of reflectance for brick-type material is to some extent confirmed by the results from target 2, a red tiled roof, which demonstrated the same reflectivity as the brick target, no.1.

Targets 3, 6 and 8, consisting of green vegetation, confirm the laboratory result whereby 1.06 micron reflectivity is two or three times that for 2.06 micron.

Dead vegetation, target 4, shows similar and quite high reflectivity at both wavelengths. Tree bark, target 7, also shows roughly equal reflectivity as was also found in the laboratory. The low reflectivity of target 7 in comparison to the laboratory measurement on tree bark is due to much of the laser energy not being intercepted by the leafless tree.

Target 5, a rather ill-defined rubble/grass/earth slope, shows much better reflectivity for 1.06 microns. This is

Table 1 - Reflectivity Estimates

				Neodymium LRF (1.06 μm)			Holmium LRF (2.06 μm)	
	Target	Range /km	cos ϕ_a	Critical aperture /mm	RX gain	Reflectivity	Critical aperture /mm	Reflectivity
1	Brick (house)	1.190	1	7	1.16	0.38 (standard) $S_0 = 15.2$	7	0.31 (standard) $S_0 = 12.4$
2	Red tiled roof	1.190	0.7	10	1.16	0.38	9.5	0.31
3	Grass slope (green) (slope≈1/3)	1.34	0.79	9	1.30	0.33	13	0.17
4	Dry bracken (brown)	1.35	0.67	9	1.31	0.39	10.5	0.31
5	Quarry face (rubble slope)	1.54	0.67	10	1.52	0.35	16.5	0.16
6	Tree (conifer)	1.33	0.67	9.5	1.29	0.34	16.5	0.12
7	Tree (leafless)	1.31	0.67	17.5	1.27	0.10	19	0.09
8	Grass slope (slope≈1/3)	1.23	0.79	10	1.19	0.24	14	0.12
9	Target 2 in light rain	1.190	0.7	14.5	1.16	0.19	20	0.070
10	Quarry face (melting snow)	1.56	0.7	10	1.53	0.35 ($S_0 = 20.5$)	>45	<0.035

quite different from the laboratory measurements made on a clean sample of Malvern rock.

The reflectivity of target 2, the red tiled roof, was also measured when the roof was exposed to light rain (target 9). Target wetness was found to reduce reflectivity by a factor of two at 1.06 microns and a factor of four at 2.06 microns. A part of the reduction in reflectivity at one micron is accounted for by an increase in the specular component of reflection due to the smooth water layer surface. An additional factor of two due to absorption in the water film for two micron radiation is quite likely. (A water layer thickness of 70 μm would be sufficient since the absorption coefficient of water at 2.06 μm equals 4.3 mm^{-1}). The light rain (visual range was about 6 km) introduced very little atmospheric attenuation; the return signal from the unwetted wall (target 1) was unchanged.

The result for a steeply sloping target of melting snow (target 10) is of some significance. The low value at two microns must be due to absorption in the considerable thickness of water in the target. Fresnel reflection of about two percent is expected from a water surface. This sets a minimum value for the reflectivity of melting snow.

Important military target materials omitted from this work are concrete, canvas and military paints.

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APPENDIX

SOME MEASUREMENTS OF THE DIFFUSE REFLECTANCE OF TYPICAL TARGET MATERIALS

Laboratory measurements of the diffuse reflectance at an angle near the normal to the reflecting surface are shown in Table A1. The values shown are relative to an alumina diffuse reflecting surface. The measurements were made in a Perkin Elmer spectrometer, the samples being oriented so that any specular components of reflection were not detected.

Table A1 - Diffuse Reflectance of Potential Target Materials

WAVELENGTH =	1.06 μm	2.06 μm
SAMPLE		
Wood(planed)	96%	72%
Green leaves	53%	15%
Tree Bark	29%	33%
Concrete	46%	38%
Red Brick	38%	31%
Rock(gneiss)	8%	18%
Olive drab paint	20%	62%

The results show a generally higher reflectance at 1.06 μm. One of the most striking differences arises in the case of vegetation in leaf, where the 2.06 μm reflectance is lower by a factor of about three. The value for olive drab paint is especially high for 2.06 μm, making the discrimination of military vehicle targets against the background somewhat easier at this wavelength.

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REPORT DOCUMENTATION PAGE

DRIC Reference Number (If known) ....

Overall security classification of sheet ....Unclassified...

(As far as possible this sheet should contain only unclassified information. If it is necessary to enter classified information, the field concerned must be marked to indicate the classification eg (R), (C) or (S).

Originators Reference/Report No. MEMO 4339	Month OCTOBER	Year 1990

Originators Name and Location

RSRE, St Andrews Road
Malvern, Worcs WR14 3PS

Monitoring Agency Name and Location

Title

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Report Security Classification UNCLASSIFIED	Title Classification (U, R, C or S) U

Foreign Language Title (in the case of translations)

Conference Details

Agency Reference	Contract Number and Period
Project Number	*Other References*

Authors PAYNE, M J P; EVANS, H W	Pagination and Ref 6

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Abstract Classification (U,R,C or S)
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Distribution Statement (Enter any limitations on the distribution of the document)

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580/48

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