AN UNDERWATER FIBERS OPTIC LIDAR FOR THE CHARACTERIZATION OF SEA WATER AND ICE PROPERTIES

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1. INTRODUCTION

This paper bears on the subject of the development, modeling and testing of the Harsh Environment Lidar, HEL. The lidar head is designed to go underwater and consists of four telescopes that are connected to the detection and emission unit via five fused silica optical fibers. Three telescopes are used for data collection, while the forth is used for laser emission. The laser source and the detection unit are located on a surface vessel. The laser beam is injected into a 100 µm in diameter optical fiber. The collimation of the laser beam is done in the lidar head via a 25 mm in diameter 45 mm focal length lens; the laser beam is linearly polarized using a polarization beam splitter. A 50 mm receiving telescope co-aligned with the laser beam is used for linear depolarization measurements. A second 50 mm telescope is used to collect off-axis scattered light while a third 50 mm telescope is used to collect inelastic scattered radiation (raman and induced fluorescence signal).

The laser source and detection units are mounted on a small optical table for easy access/modification. Various laser sources and lidar detection techniques (Q switch pulses or frequency modulated) could be easily implemented. The lidar head can be deployed under water or mounted on a flying platform.

The HEL has polarimetric, spectral and multiple scattering measurement capabilities. It is designed to be either engulfed in very dense aerosol or underwater. In the following we focus on water application; more precisely on the detection of sea ice from an underwater position. The application is the detection of ice for small autonomous underwater vehicles or probes. The questions to be answered are the following:

- Given that water and ice have very close refractive indexes; what is the reflectivity of immersed ice?
- For a given lidar parameter geometry what are the maximal distances at which ice can be detected?
- Can the depolarization of ice be used to determine if there is an ice cover?

2. DESCRIPTION OF THE HE LIDAR

Figure 1 and 2 show the open lidar while Figure 3 shows the complete lidar head with it large 15 cm fuse silica window, it is sealed protective tube containing all the fibers and on Figure 4 the laser source and the detectors are shown. The lidar consists of a 100 Hz repetition rate FDSS 532-150from CryLas GmbH providing (150 µJ) at 532 nm with a pulse width of 1 to 1.5 ns. It is injected into a 200 µm fused silica fiber (200/220/320) from CeraOptec Industries a 105 µm fiber (105/125/250A) could also be used.

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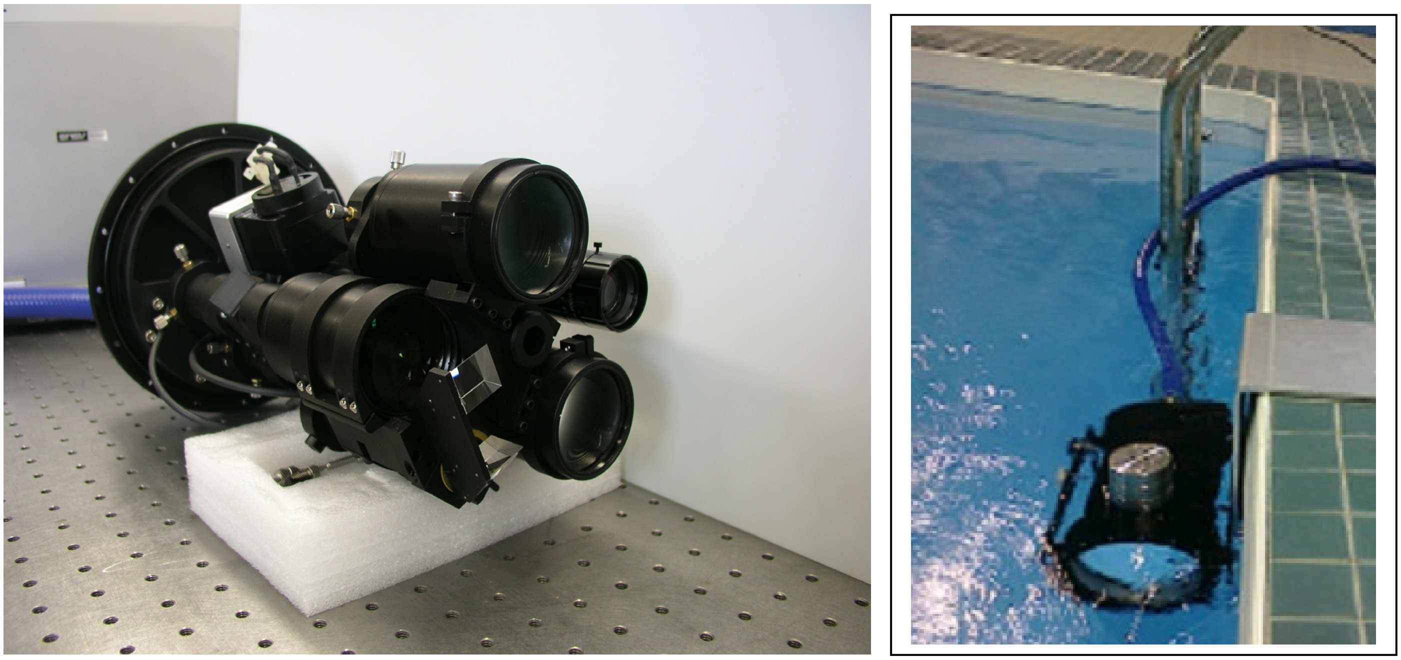

Figure 2. Semi front view of the inside of the HE lidar head and a view of the HE lidar head immersed.

3. PERFORMANCE MODELISATION

The lidar equation for single backscattering from water and for a solid target situated at distance z_T is:

$$P(\lambda, z) = P_0(\lambda)\xi(\lambda, z)\eta \frac{A_{rec}}{z^2}\left\{\frac{c_w \tau}{2}\sigma_s \beta(z) + \frac{\rho(\lambda)}{\pi}\delta(z - z_T)\right\}\exp\left[-2\int_0^z \sigma_{ext}(\lambda, z')dz'\right]. \quad \text{Equation 1}$$

where

- $c_w = c / n$ is light speed in the water, n is refractive index of the medium;
- τ is laser pulse duration, 1 ns;
- $\xi(\lambda, z)$ is the overlap function between the transmitted laser beam and the field of view of the receiver; it is set equal to: $\xi(\lambda, z) = \frac{\pi({R_{rec}}^2 - {R_{emis}}^2)}{\pi {R_{rec}}^2}$;
- R_{rec} and R_{emis} are the radius of the collecting and emissive optic. They are set equal to 25.4 mm and 12.7 mm respectively;
- $\eta = 0.1$, is the optical efficiency (quantum efficiency x optical transmission)
- $A_{rec} / z^2 = \frac{\pi {R_{rec}}^2}{z^2}$ is the acceptance solid angle of the receiver optics with a collecting area A_{rec};
- $\sigma_{ext}(\lambda, z)$ is the extinction coefficient of the participating medium at the wavelength λ for the range zr;
- $\rho(\lambda)$ is the reflectance of the target;

- $\delta(z - z_T)$ is a Dirac function defining the position of the target
- $P_0(\lambda)$ is the power emitted by the laser source at wavelength λ;
- $P(\lambda, z)$ is the lidar return power from distance z at wavelength λ.
- $p(\pi, z)$ is 'water' phase function at scattering angle 180 deg, (sr^{-1});
- σ_s is the scattering coefficient of 'water', (m^{-1}).
- σ_{ext} is the extinction coefficient (scattering + absorption) of 'water', (m^{-1}).

We want to calculate the maximum distance at with ice floating on water can be detected from below the surface. To do so, the following lidar parameters were set.

Table 1 Lidar Parameters for modelization

Parameters	Description	Unit	Value
Lidar system	Laser pulse energy	μJ	80
	laser pulse width	ns	1
	laser average power	W	80000
	receiving optics radius	mm	25.4
	η , optical efficiency		0.1
	$P_{\min}$, Detector limit	W	5e-8
	wavelength	nm	532

Table 2 Inherent optical properties of selected waters, values are for λ = 514 - 532 nm (Error! Reference source not found. **and 2)**

	Pure sea water	Clean ocean	Turbid ocean
σ_s (m^{-1})	0.0025	0.084	0.778
σ_{ext} (m^{-1})	0.043	0.184	0.978
$p(\pi, z)$ (sr^{-1})	0.1142	0.0027	0.0015

The immersed ice reflectivity has been estimated experimentally: for a given range a 8 cm thick ice block gave around 10X less signal than a target made of white Styrofoam (the white Styrofoam has a reflectivity very close to a white 99% reflectivity Spectralon). We have also observed that at 4 cm thick ice block give approximately 2X less signal than a 8 cm in thickness. We did not observe any significant difference between sea water ice and water ice. So a reflectivity of 0.05 is a representative value.

At $z = z_T$ the signal from the target is over 100 X larger than the signal from the 'water'. So at $z = z_T$, ignoring the 'water' backscattered contribution and setting the measured power to the minimum detectable power, $P_{\min}$ =5E-8 W , Eq. 1 become after rearrangement:

$$z_T^{\ 2} - \frac{P_0(\lambda)}{P(\lambda, z_T)} \xi(\lambda, z_T) \eta A_{rec} \frac{\rho(\lambda)}{\pi} \exp\left[-2\int_0^{z_T} \sigma_{ext}(\lambda, z')dz'\right] = 0 \qquad \text{Equation 2.}$$

Assuming a constant σ_{ext} over 0 to z_T, Eq. 2 is solved for z_T using Newton-Raphson method for the water parameters of table 2.

Table 3 provide the maximal distances, z_T, at which it should be possible to detect submerged ice for a given reflectivity.

Table 3Maximum detectable distance of submerged ice for different water bodies.

σ_{ext} ((m^{-1})	$\rho(\lambda)$	z_T (m)
0.043	0.05	219
0.043	0.1	233
0.15	0.05	58
0.15	0.1	61
0.4	0.05	12
0.4	0.1	13

4. RESULTS FOR THE DISCRIMINATION OF SOLID TARGETS

A preliminary HEL underwater experiment has been performed in an indoor swimming pool. Sea water ice of 4 and 8 cm thickness, unsalted ice of 8 cm thickness and 2.5 cm thick white Styrofoam were set at a distance of 20 m from the lidar head. Strong signals were obtained for both polarizations. The white Styrofoam shows nearly 10 x stronger signal than the 8 cm thick ice. The signal from ice appears to be, to some extent, proportional to ice thickness. The signal from salt water ice and fresh water ice showed no significant difference. Ice showed a significantly stronger depolarization ratio that the white Styrofoam.

REFERENCES

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