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Small Target Detection in Shallow Water Using Air-borne Laser

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1. Introduction

In detecting underwater taegets, sound is still the most reliable method because it can propagates to long range with little energy loss. However, sound needs much effort for it to be applied so that its platform is mostly limited to ships. In oder for ships to successfully operate thir sonars, they have to keep their speed to less than that of normal crusing. This is the main reason why sound has low efficiency over large searching area. In addition, very shallow water refuses ship's approach.[1]

Air-borne laser can be useful solution over the hostile conditions for sound. The blue-green laser, its wave-lenth is between 445~532nm, is known to be able to penetrate water depth from tens(shallow water) to hundreds(open ocean) meters. Due to its small wave-length, it can resolve very small underwater target.

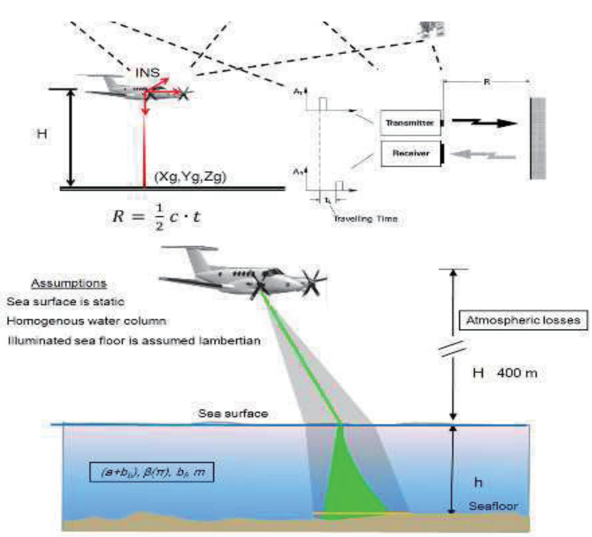
We present the feasibility of air-borne laser to detect small underwater targets through sea trails in a shallow water. We also deploy wire-walker which has serveral sensors of turbidity, temperature and depth. The wire-walker goes up and down in the water column responding to wave actions and bouyancy. From the sea trial, we can estimate the maximum water depth of laser penetration over the sea environment.

2. Bathymetry Survey Using Laser

2.1 Concept

Air-borne laser system transmits laser pulses into the sea surface and detects reflected pulses through receivers. In order to estimate water depths, it transmits two types of wave-length laser, infra-red and blue-green. The infra-red reflects totally from the sea surface but the blue-green penetrates into water column reflecting from the sea bottom. Using the time delays between the reflected signals, the system can estimate the water depths.

Air-borne laser system has its own inertial navigation system and uses global positioning systems(GPS) to exactly reference received signals. Figure 1 shows the concept of airborne laser system in surveying bathymetry.[2] In estimating water depths, the system has three assumptions. 1) Sea surface is static. 2) Water column is homogeneous. 3) Sea bottom roughness is Lambertian.



Fg.1 Concept of air-borne laser system for bathymetry survey.[2]

2.2 Laser Propagation in Water

Laser pulse inevitably undergoes dispersion, scattering and reflection in the water column and sea floor. The received signals on the detector can be expressed by summing all the terms of reflection from sea surface(Fresnel)($S_{Fr}^{\delta}(t)$), backscattering in the water column($S_{bs}^{\delta}(t)$), and reflection from sea bottom($S_{bot}^{\delta}(t)$).[3]

$$S^{\delta}(t) = S_{Fr}^{\delta}(t) + S_{bs}^{\delta}(t) + S_{bot}^{\delta}(t)$$

The water depth can be estimated from the time delay between the signals from sea surface and sea floor. The time delay in turn can be estimated from the waveforms on the detector. The following figure presents waveform examples of each component and final summation. Laser speed in water can be calculated using the Snell's law, where only one consideration is refraction ratio between air and water. If there exist another peak between the Frenel and sea bottom, we can assume another object in the water column.[4]

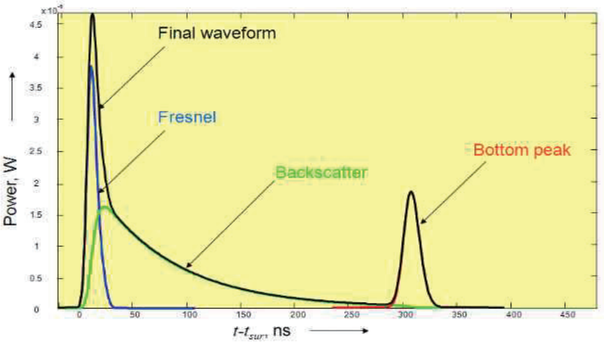


Fig.2 Waveform examples showing components from Fresnel, backscattering, bottom reflection and their final sum.

3. Sea trial in Shallow Water

We conducted a sea trial in Korean shallow water. We employed a commercial air-borne laser system, plastic sphere of diameter 80 cm as small target, and wire-walker to get environment data.

Figure 3 shows bathymetry distribution estimated by laser pulses reflected from sea bottom. We can see that the system can resolve up to 30m water depth at the sea trial. The blank in the figure denotes the area of missing data likely caused by calibration failure with GPS data.

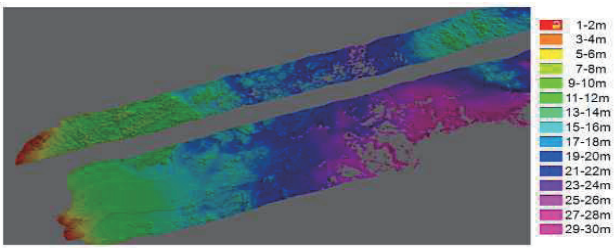


Fig.3 Bathymetry distribution estimated by airborne laser system.

Figure 4 presents examples of waveform and 3-dimensioanl structure over the sphere object. From the one point waveform, we can see clear peak from the target between the peaks from sea surface and bottom. Meanwhile, the 3-dimensional structure may give object depth and even its size by

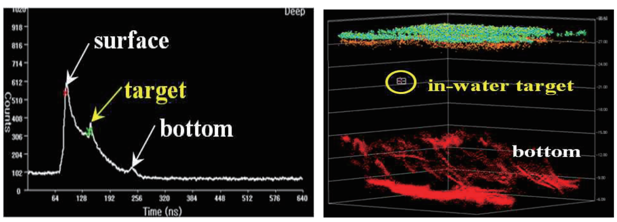


Fig.4 Waveform(left) and 3-dimensional structure (right) over the sphere object of diameter 80 cm.

using x-y-z data estimated from waveform at each grid point.

Figure 5 shows variations of temperature, turbidity and photon from sensors loaded on the wire-walker. It is interesting that turbidity shows very high correlation with temperature. This fact implies that water mass moving may decide turbidity because temperature variation is mainly caused by relative locations of water masses. The photon gives absolute daily variation as we expected.

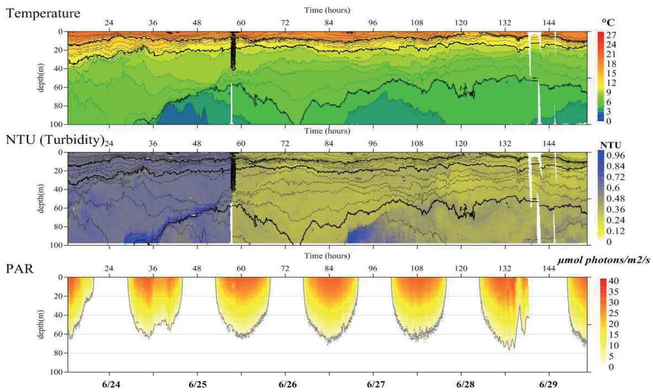


Fig.5 Temperature(top), turbidity(middle) and photon(bottom) from sensors loaded on the wire-walker.

4. Conclusions

We confirm that air-borne laser can be useful in searching small targets in shallow water. The maximum water depth which laser can reach depends on the laser power and water turbidity. In order for the laser system to be more operational to detect targets in water, it needs real-time processing by employing the so-called 'change detection' comparing the exsisting and *in-situ* bathymetry data.

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