Title: Satellite laser tracking system for aquatic organisms

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Organization: Kindai University

(Yes) We apply for Student Prize.

(No) Please keep our idea confidential if we are not selected as finalist/semi-finalist.

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Need

Management of fishery resources has increasingly become a large issue over the world. In recent years, stable supplies and sustainable use on what in global scale are difficult as the fishery production exceeds limit to maintain and restore fishery resources based on self-healing mechanisms in ecosystems [1]. Therefore, research and investigation of aquatic organisms has become more important research field such as ecological studies of aquatic organisms using data loggers [2]. Archival tag and archival popup tag as data loggers are used in those research. The archival tag is a type of logger equipped with a target organism, and it is necessary to collect an archival tag to obtain data. The archival pop-up tag is a type of logger equipped with a target organism, data from a target organism automatically floats on the water surface and collects data. Both require time and effort to collect data and it is difficult to check the data in real time.

Mission Objectives

We propose a system architecture with a laser source equipped at the satellite, a retroreflector, and a detector to measure the position of aquatic organisms in real time. In this system, a retroreflector sheet on aquatic organisms reflects light irradiating from a green laser source, and the detection system at the laser source detects the reflected light. We developed retroreflector suitable in their size for the attachment to aquatic organisms, since they have little stress on aquatic organisms and can minimize influence on their swimming. In addition, it is possible for retroreflector to operate so long time as not to require batteries.

Concept of Operations

The basis of Airborne Laser Bathymetry (ALB) measurement is the same as conventional aerial laser measurement (near infrared laser). The ALB measures the retroreflector by simultaneously irradiating two wavelength band lasers (near infrared laser and green laser). ALB's green laser that permeates the water can acquire the terrain of the ocean floor and riverbed. In our experiment, green laser was irradiated from about 500 m above the sea using ALB in order to detect the position of the chicken grunts (*Parapristipoma trilineatum*) using the selected retroreflector. The green or blue lasers are irradiated from about 300 km above the sea using the satellite laser tracking system for aquatic organisms.

Key Performance Parameters

Figures 1 and 2 show experimental configuration using the ALB. A Chicken grunt equipped with capsule lens type retroreflector was measured with the ALB in a fish cage (3 m × 3 m) and four in the experimental pond. The specifications of the ALB device (Leica Chiroptera II) is also described in Fig. 1 as well. The experimental measurement was conducted twice at 10 minutes interval under the cloudy weather condition, using the ALB at a height of 500 m with the moving speed of about 200 km / h and Green laser Intensity of 5 W (500 mJ) at the time of irradiation whose ground footprint diameter is about 2.25 m

Figure 3 shows the measurement results of the reflected light from the fish cage (3 m × 3 m). A1 (B) and A2 (C) are points that exhibit strong reflection intensity and are considered to be reflections from the chicken grunts to which the reflecting sheet is equipped. Here, A1 (B) and A2 (C) indicate the first and second measurements. Considering the difference of the location of the chicken grunts between those two measurement intervals, we could obtain the swimming speed of them and find the retroreflector had less effect on the swimming.

Figure 4 shows the measurement results in the experimental pond, and both B and C in the figure show strong reflection intensity. This experimental pond is about 2000 times larger than a fish cage, so it is close to the actual marine environment. Here, B indicates the first measurement and C indicates the second measurement. Also, the same numbers represent the same chicken grunts. The position of chicken grunt was judged by the movement of reflection points with the help of the reflection intensity from the fish cage obtained in the experiment of Fig. 3.

Leica Chiroptera II		
Wavelength	515 nm	
Pulse	35000 Hz	
Class	4	
Depth range: D_{max}	2.2/k	
Max depth range	23 m	
Aerial digital camera (RCD30)	IHO order 1a	
IHO order 1a (International waterway standard)	Flat accuracy	±2.5 m
	Height accuracy	±0.25 m

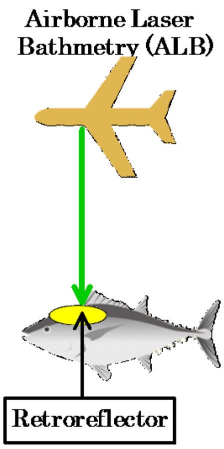

Fig. 1 Experiment using ALB.

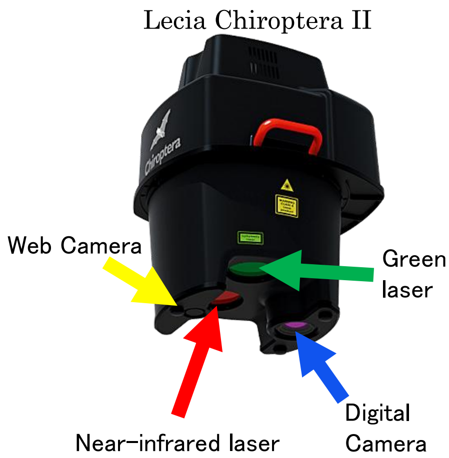

Fig. 2 ALB equipment.

Table 1 summarizes the relationship between depth of the chicken grunt and reflection intensity of the ALB measurements obtained in Fig. 3 and 4. From the measurement results of the fish cage (3 m × 3 m) in Fig. 3, the reflection intensities at a depth of about 4 m were 7800 to 8800 in arbitrary unit and similar range of values were obtained for the measurement of the experimental pond. Thus, the developed retroreflector on the chicken grunts successfully contributed to detect the location of the chicken grunts without heavy burden for them. We believe periodical ALB measurements help to obtain the location of aquatic organisms in real time.

Table 1 Data of Fig. 3 and 4.

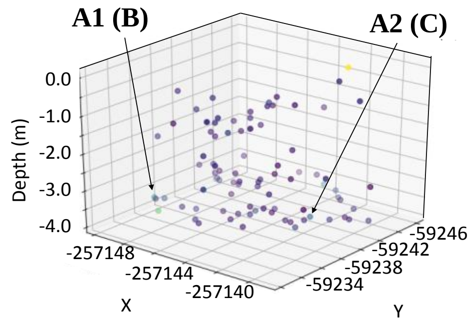

Fig. 3 Measurement results at a fish cage.

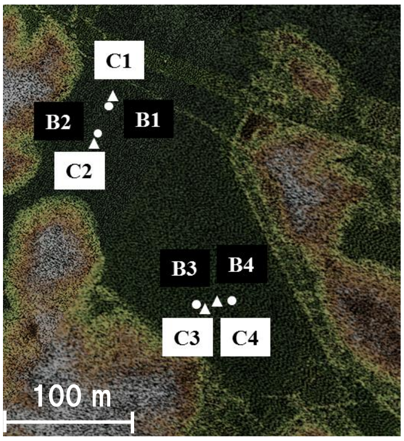

Fig. 4 Measurement results at the experimental pond.

	Depth (m)	Intensity (a.u.)
A1 (B)	-3.906	7851
A2 (C)	-3.701	8795
B1 ○	-1.651	10865
C1 △	-1.720	8768
B2 ○	-1.567	8160
C2 △	-1.608	8568
B3 ○	-0.818	9546
C3 △	-0.686	9657
B4 ○	-0.876	8380
C4 △	-0.700	9510

Space Segment Description

① System Architecture

Fig. 5 and 6 shows the proposed system architecture employing the switchable retroreflector. A high-power and low-divergence laser within a terminal on an aircraft or satellite launches the visible light downward. The spot size of the laser light is spread, and the part of light energy reaches to the retroreflector. Then, the modulated light is reflected to the terminal with the receiver.

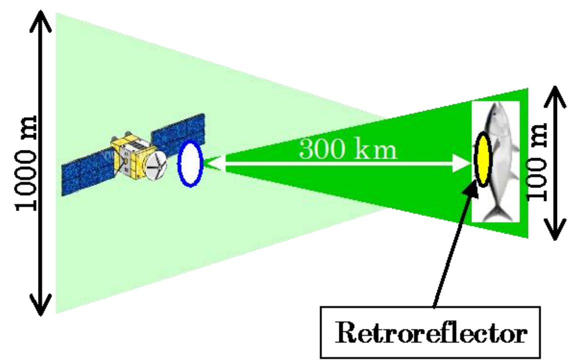

Fig. 5 Satellite laser tracking system for aquatic organisms.

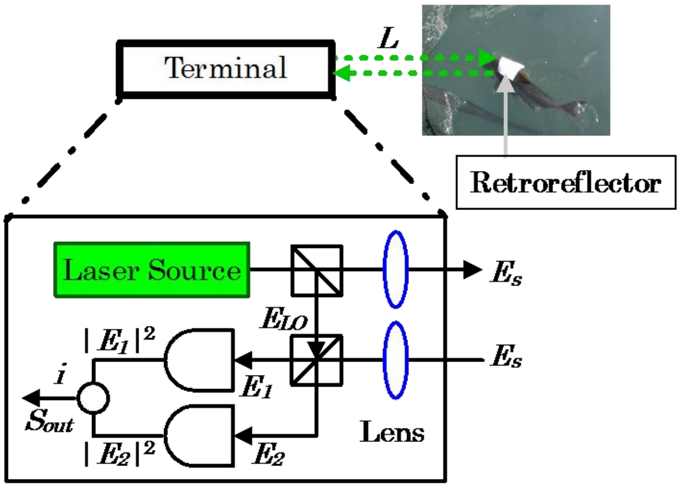

Fig. 6 System configuration proposed in this paper. The optical transmission link is formed by a terminal with the green laser and self-homodyne detector and a switchable retroreflector.

② Switchable Retroreflector for Optical Modulation

We assume retroreflector with the optical modulation functionality on the surface as a data transmitter on the aquatic organism. The recent study achieved the high-speed modulation which can support 45 Mbps data rate [3] and the reflection efficiency of up to 60 % [4]. Those studies support the feasibility of the proposed architecture.

③ Self-Homodyne Receiver

We propose the self-homodyne receiver which fully utilizes the proximity of receiver with the signal light source. In other words, the part of laser light is utilized as the local oscillator light and the optical phase is locked with the input signal reflected by the retroreflector. The optical phase of the local oscillator light is controlled by the optical phase lock loop with acousto-optic modulator [5]. The acousto-optic modulator locks the optical phase of the local oscillator light. In order to obtain high signal-to-noise ratio (SNR) of the reflected signal, the pulsed signal and local oscillator light is considered in this paper.

Orbit/Constellation Description

1. Optical Power Loss over Transmission Line

The origin of predictable energy loss between laser source is the (1) beam divergence, (2) diffraction and absorption within the air, (3) reflection on the surface of water, (4) loss in the retroreflector, and (5) diffraction and absorption within the water. In addition, we have to consider the effect of (6) turbulence of air. Now, we incorporate each factor as follows.

(1) Beam divergence loss: The height of the terminal with the laser is assumed as 3 km. The beam divergence angles of the laser and retroreflector are assumed as 0.33 mrad ad 3.3 mrad which are achievable values in current industry. The direction of the laser beam is assumed as vertical downward from a helicopter or aircraft. The area of the retroreflector and the lens of the receiver are assumed as 0.01 m^2 and 0.1 m^2. This leads the loss of 20 dB for outward and 30 dB for homeward direction.

(2) Diffraction and absorption in the air: This factor is considered as the 40 % (L_2=2.2 dB) of loss coefficient assuming the clear weather condition.

(3) Reflection on the surface of water: This factor is considered as the 16 % of loss coefficient (L_3=0.8 dB).

(4) loss in the retroreflector: This factor is considered as the 60 % of loss coefficient (L_4=4.0 dB).

(5) Diffraction and absorption within the water: This factor is assumed as L_5=1.31d [dB] of the water in the clean ocean, where d is the depth of water.

(6) Turbulence of air and water: Since this is dynamic factor requires further investigation, we incorporate this factor within design margin L_6=L_m= 40 dB.

Thus, we obtain total optical power loss over transmission line in dB as follows,

$$L = 60 + 1.31\ d + L_m. \tag{1}$$

2. Optical Signal-to-Noise Ratio

The optical signal-to-noise ratio (OSNR) of the pulsed light signal with the wavelength of 515 nm is given as

$$OSNR\_s = 10\log\left(\mathrm{P_s}/\mathrm{hv}\zeta\mathrm{b}\right) \tag{2}$$

where P_s is the average output optical power at the laser source, the reference bandwidth R=ζb is considered as the same value with the baud rate of data transmission and, ζ is duty ratio of the pulsed signal light, b is the reciprocal of time slot width. Thus, the OSNR of arrived signal light at the receiver in dB is given as $$OSNR_r = OSNR_s - L. \quad (3)$$

3. Numerical Results

Fig. 7 shows the OSNRs at the receiver versus the depth of the retroreflector in the case of 10 kbps, 100 kbps, and 1 Mbps. The OSNR rapidly decreases as the depth of the reflector increases.Fig. 8 shows the relationship between the possible transmission data rate versus the depth of the switchable retroreflector, where the resistance of the receiver circuit is assumed as 50 Ω. The 20 dB OSNR at the input of the receiver is assumed to obtain the possible transmission data rate, which is 123 kbps at the depth of 10 m if the source laser power is 1 W.

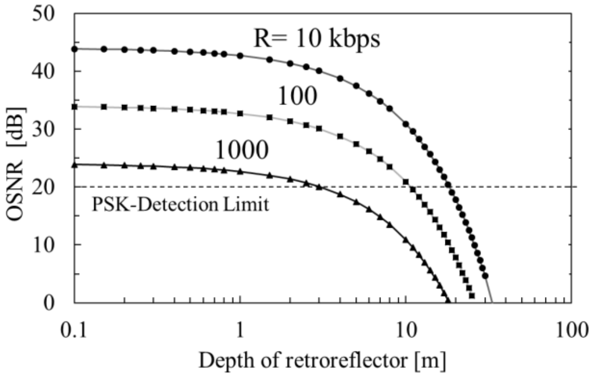

Fig. 7 OSNR in the case of 10, 100, and 1000 kbps with CW.

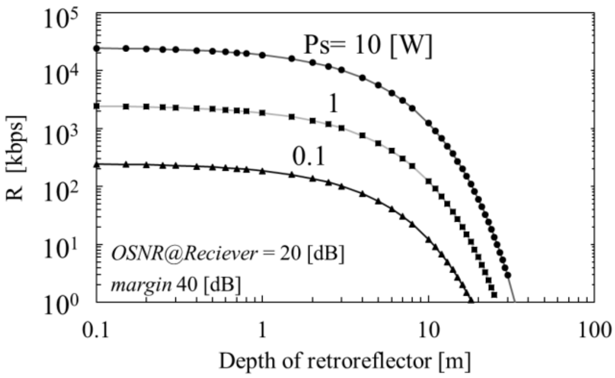

Fig. 8 Possible transmission data rate in the case that the CW source laser power of 0.1, 1, and 10 W.

Implementation Plan

We conducted the experiments with the ALB to detect the position of chicken grunts equipped with capsule lens type retroreflector sheets by irradiating green laser located about 500 m above sea level. We successfully demonstrated the methodology to track the aquatic organisms in real time with the ALB measurement. And the aero-aqua optical transmission system architecture employing the switchable retroreflector and the self-homodyne detector. The employment of pulsed signal and local oscillator light contributes to increase the margin of the system. The total estimated costs for satellite laser tracking system is at most 100k US dollars.

References

[1] S.Saitoh, Consultants Hokkaido, vol. 107, pp. 6-9 (2007).

[2] S.Chow, Fisheries Resource Management Discourse Newsletter, vol. 31 pp. 29-38 (2003).

[3] W. S. Rabinovich et al, “45-Mbit/s cat’s-eye modulating retroreflectors,” Opt. Eng. 46, 104001, 2007.

[4] P. Schultz, et al., “Investigation of five types of switchable retroreflector films for enhanced visible and infrared conspicuity applications,” *OSA Applied Optics*, vol. 51, No. 17, June 2012.

[5] W. Imajuku et al., “Error-free operation of in-line phase-sensitive amplifier,” IET Electron. Lett., vol. 34, No. 17, pp. 1673-1674, Sep. 1998.