Compact Optical Imager for Real-time, 3-D Range, Intensity and Fluorescence Mapping of the Ocean Floor

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LONG-TERM GOALS

Our research is directed toward utilization of state-of-the-art optoelectronic technology for real-time 3-D imaging in aqueous environments. We strive to construct a compact instrument capable of real-time imaging and classification of man-made and natural objects in a wide range of marine and freshwater environments. We expect that this work will have relevance to the in-water investigation and surveillance needs of branches of the U.S. Military, U.S. Intelligence agencies, as well as state and local law-enforcement agencies.

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14. ABSTRACT

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OBJECTIVES

Our Real-time Ocean Bottom Optical Topographer (ROBOT) prototype demonstrated the feasibility of our technical approach. Current work is focused on the development of an improved version of our proof-of-concept system. The desired operating limits for the sensor include a working altitude of at least 4 to 5 meters while maintaining centimeter-scale image resolution. It is also desired to maintain these parameters in moderately turbid waters (water attenuation of 0.6 meter^{-1}). Overall system size will be reduced to permit use on a wider range of platforms.

APPROACH

The specific technical approach in this project is triangulation (Kaltenbacher et al., 2000). A laser is used to project a line of light onto the area of interest. A camera positioned a known distance away, and at a known angle with respect to the laser beam, records images of the laser line. Processing of the images with knowledge of the relationship between the laser and camera permits accurate 3-D mapping of imaged objects. In this work, an autonomous underwater vehicle (AUV) is used to move the sensor package over areas of interest.

Key personnel: E. Kaltenbacher (Lead Engineer), J. Patten (Software Engineer), D. Costello (Ocean Optics Researcher), K. Carder (Lead Scientist) and Center for Ocean Technology (COT) Engineers and Technicians.

WORK COMPLETED

We have completed the design, construction and initial testing of the ROBOT sensor (Figure 1). The sensor, illustrated in an AUV nosecone, is comprised of a laser (pink), batteries (orange), camera and electronics (blue). Also included is an attenuation meter shown between the two batteries. Design of the instrument was completed in early June and construction was complete at the beginning of August. In late August and early September we deployed the sensor in our flume tank, Tampa Bay and the Gulf of Mexico with COT's ROVEX drive section. These deployments were used to test the intial operation of the sensor and work out any operational glitches.

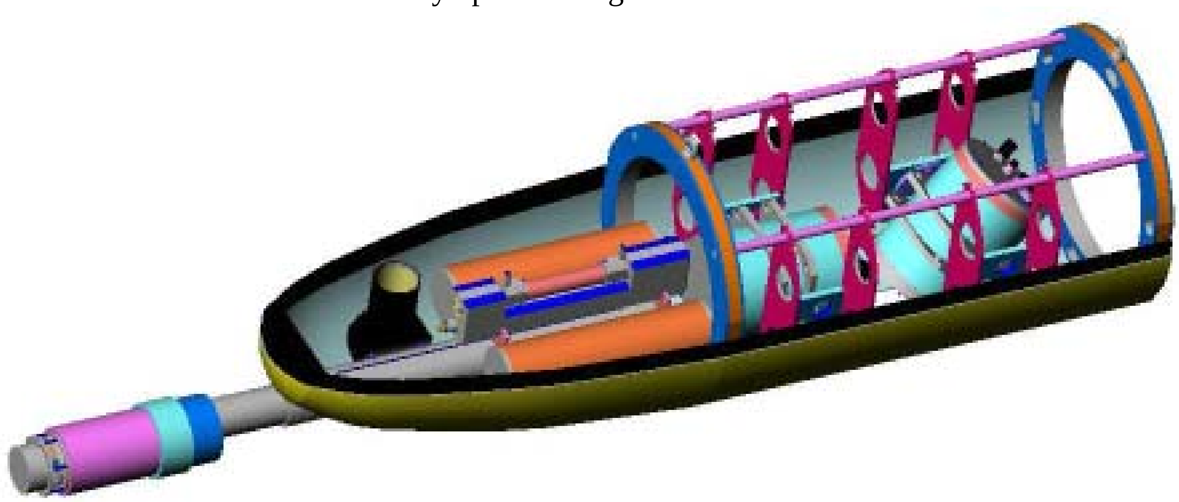

Figure 1: A model of the ROBOT sensor.
[The model of ROBOT shows the laser (pink), batteries (orange), control-electronics housing (blue) and camera housing (blue) assembled into a AUV nosecone.]

We are in the process of publishing three works documenting studies of the range of conditions suitable for operating our ROBOT sensor. We have investigated the effects of natural illumination on image contrast using artificial illumination (Reinersman et al., in-press) and the use of unmanned underwater vehicles to determine spatial distributions of apparent optical properties of water (English et al. in-press). We have also examined feature classification using 2-D and 3-D moment invariants (Hou et al., in-press).

Our focus over the remainder of the funding period will be to continue deployments of the sensor under a wide variety of conditions. Data gathered from these missions and optical models will be used to refine image-processing algorithms. We are developing more sophisticated algorithms that can process the line images under the varied conditions (turbidity, reflectance) encountered in the ocean. We are also working towards removing vehicle effects (roll, pitch, velocity) from our images. Fluorescence imaging might extend the sensor's operation in turbid waters and we will investigate using ROBOT's laser as an excitation source in the turbid waters of Bayboro Harbor.

RESULTS

Since we have only recently began testing of the instrument our results illustrate initial characterization of the sensor's operation. Figure 2 shows a ROBOT image of a pyramid-like object image during flume-tank testing. Starting from the bottom of the pyramid the step dimensions are 6, 13, 19, 25, 38 and 50 mm. From this testing we learned that in clean water sensor can provide dimensionally accurate images with a resolution of at least 6 mm.

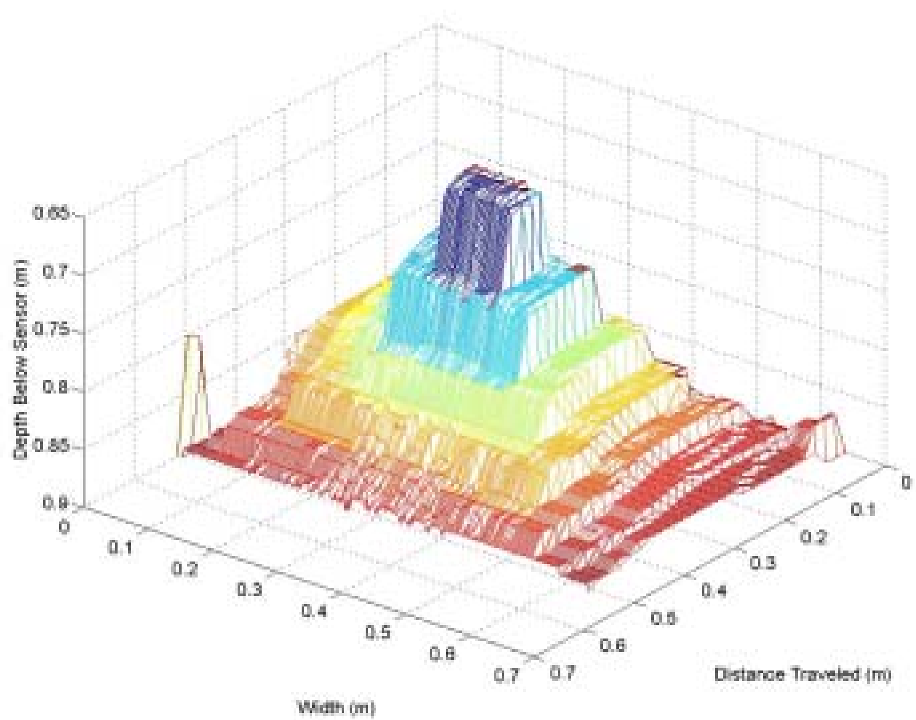

Figure 2: A ROBOT image of a stepped pyramid-shaped test target.
[This image shows a ROBOT image of a stepped test target designed to characterize the vertical resolution of the sensor. Starting with the bottom, the step sizes are 6, 13, 18, 25, 38 and 50 mm.]

Figure 3 is an image (before processing) of the laser line illuminating a test target placed in Tampa Bay. The target is a cone roughly 0.3 meters high and 0.5 meters in diameter. The range from the sensor to the target was approximately 1.5 meters and the attenuation coefficient (c) was 2.0 meter^{-1}. Calculations predict less than 0.1% of the laser light will reach the camera in this configuration. Under these imaging conditions, forward scattering from the highly turbid water broadens the laser line to make precise dimensional imaging more difficult. However, basic shapes can be readily identified revealing the need for further investigation. Furthermore, for most applications it is expected that water conditions will be far better than these encountered in Tampa Bay.

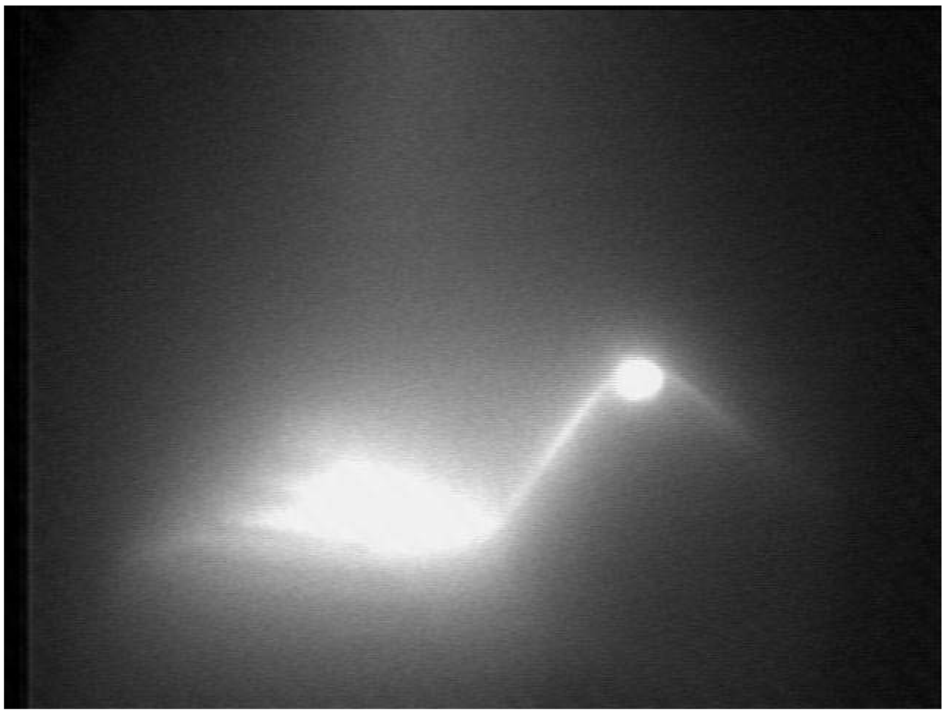

Figure 3: An unprocessed ROBOT image of a test target.
[This image shows the laser line illuminating a test target in the turbid waters of Tampa Bay. Although the line has been broadened due to the large amount of particulate in the water, the shape of the object is clearly revealed.]

Accurate navigation is a crucial element of successful imaging of identified stationary targets or of targets that may be moving, such as a ship's hull. During our deployment in the Gulf of Mexico, we successfully demonstrated the ability to identify a target, remotely navigate the AUV (with ROBOT) over the stationary target, and capture images of it. Acoustic tracking formed the heart of the target-tracking system, which had an accuracy of about 1 meter. This system also accounted for the motion of the research vessel, from which we controlled the sensor, to maintain a positive lock on the target's position. GPS data were also used to geodetically locate the target. Sensor and navigational control were established through an RF link to the AUV through distances approaching 0.5 km. In future work scanning ship's hulls, we will use GPS receivers tied to at least two locations on the ship to maintain sensor orientation/propulsion with respect to the ship for proper scanning.

IMPACT/APPLICATIONS

The ROBOT instrument presented in this work can be used to accurately provide 3-D images in a variety of conditions. Applications of this sensor include object detection (e.g. mines, coral), contour mapping (e.g. sand waves), crash site investigations, and port security (hull inspection, sea wall mapping). ROBOT data can also be used in shallow coastal waters to ground-truth remote sensing data (Carder et al. in-press). Our instrument is simple, portable, relatively inexpensive and suitable for use on a wide variety of platforms.

TRANSITIONS

The technology development in this work can be extended to analysis of terrestrial areas considered too dangerous for human investigation. This instrument can analyze debris and other aspects of crime scenes or other hazardous areas. Local law enforcement agencies have expressed interest in utilizing ROBOT for in-water forensics. ROBOT forms the basis for a project with the U.S. Coast Guard utilizing ROBOT for port security by scanning ships' hulls and seawalls.

RELATED PROJECTS

Development efforts on navigation and AUV control were funded under ONR #N00014-02-1-0267 "Autonomous Ship Detection System". Studies in modeling and measuring seawater optical properties were funded by ONR #N000140-02-1-0211 "Optical Variability and Bottom Classification in Turbid Waters: Phase II".

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