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 development of an automated sensor for capturing 3-D images of man-made and natural objects in aqueous environments. We strive to construct a compact instrument capable of real-time imaging and classification of imaged objects using state-of-the-art optoelectronic technology. 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.

OBJECTIVES

Our Real-time Ocean Bottom Optical Topographer (ROBOT) prototype demonstrated the feasibility of our technical approach. The objectives of the current work include: a) development of an embedded real-time image-processing system, b) repackaging the current sensor to fit within a 12 ¾" AUV, c)

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development of optical models describing ambient light conditions and laser-beam attenuation to determine operating conditions suitable for ROBOT, d) fusing image and navigational data to form mosaic images of scanned targets.

APPROACH

The operating principle behind our optical 3-D imager is triangulation and has proven to be effective for generating accurate 3-D images (Kaltenbacher et al., 2000). We will utilize digital signal processor (DSP) integrated circuits to implement our embedded version of this instrument. This approach facilitates a compact low-power design without the overhead of standard computer hardware and operating systems. In the current system, the major components are packaged in separate pressure vessels. A single (albeit more complex) vessel will be used to repackage the system to fit smaller AUVs.   By utilizing environmental and vehicle data we endeavor to construct a robust sensor system with predictable operational characteristics. Monte Carlo analyses will be used to quantify scattering effects in the water to predict sensor performance in varied environments. Global positioning data from GPS receivers will be used concurrently with acoustic local tracking to geodetically reference the sensor's position enabling precise target locating and forming image mosaics from individual scans.

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

Development of the DSP-based embedded processor is the major effort during this year's effort. We have successfully utilized a prototype development system to interface a Texas Instruments' C6711 floating-point DSP to our camera. We have demonstrated the ability to digitize and display video in real-time using this DSP.   Unfortunately, our work has suffered from long, unanticipated purchasing delays and development-hardware failures. Specific DSP tasks we still need to address include: a) optimization of code to permit more advanced image processing in real-time, b) generation of custom printed circuit boards with video A/D converters, memory and the DSP, c) interfacing the DSP with our standard microcontroller for overall instrument control and communication with external sensors.

ROBOT has been repackaged into a form factor suitable for mounting in a 12 ¾" diameter AUV. Figure 1 illustrates a 3-D model of the repackaged sensor. Along with the physical reconfiguration of our instrument, we were able to increase our video frame rate from 20 Hz to 30 Hz through refinements of software. These refinements include enhanced buffering schemes for image data and more efficient algorithms that process the images to determine laser-line profiles. Additionally, we designed new optics for generation of the laser line. The objective of this design was to create a line with uniform intensity. The intensity characteristics were improved, but it is likely another design iteration is needed to obtain the uniformity we desire. The smaller ROBOT has been deployed several times during the summer in Tampa Bay and coastal waters in the Gulf of Mexico. Initial deployments identified problem areas with the new design and these have subsequently been corrected.
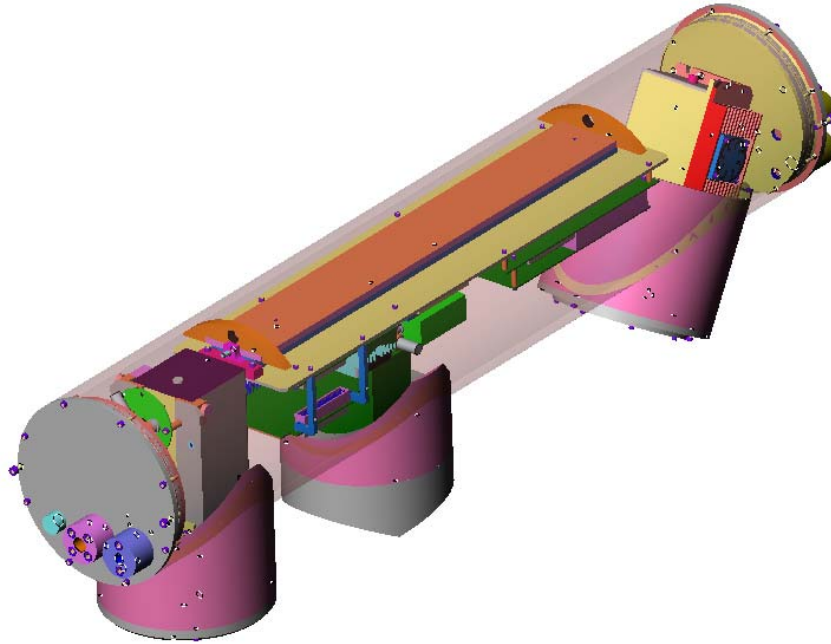
Figure 1. A model of the ROBOT sensor.
[The main tube is 7"in diameter by 35" long. The camera is located at the near end of the tube and is pointed straight down. Positioned at angle at the rear of the tube is the laser. A DVL is positioned in the middle of the instrument.]

We have investigated the effects of natural illumination on image contrast using artificial illumination (Reinersman and Carder 2002; 2003.) and the use of unmanned underwater vehicles to determine spatial distributions of apparent optical properties of water (English et al.). The eventual outcome of this modeling will provide the ability to predict whether our sensor can operate under the given conditions during a particular deployment.
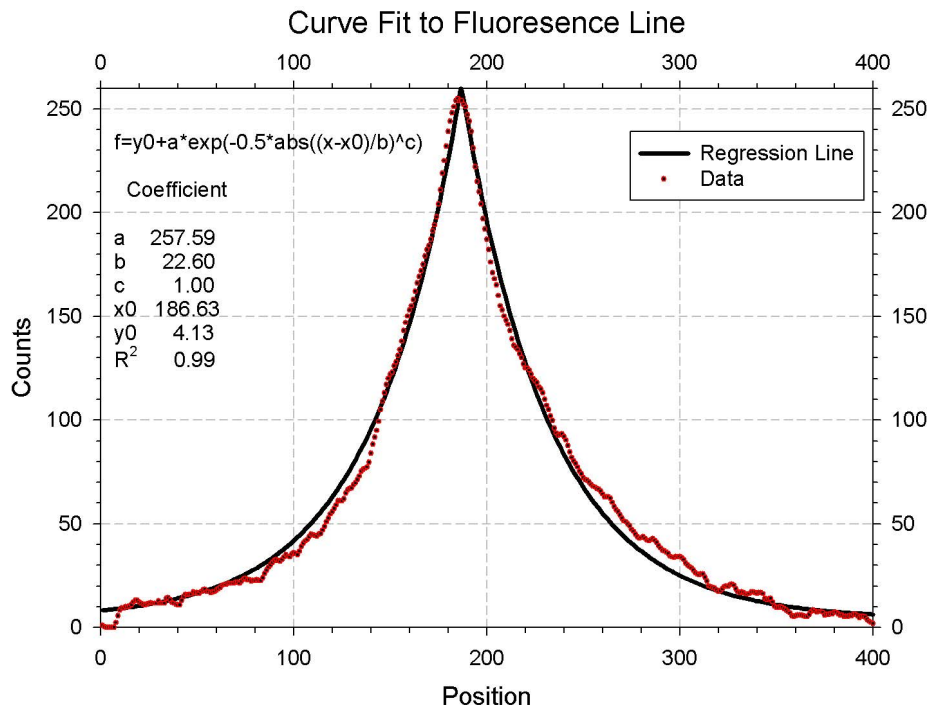
We developed algorithms that remove vehicle motion effects from our images. This post-processing enables accurate scaling of imaged targets by removing sensor roll, pitch, and yaw and vehicle-velocity effects. Coupled with vehicle data are navigation data from GPS receivers and local acoustic tracking hardware. Combined, these data sets enable us to piece together separate runs of our sensor to form a mosaic image of the scanned area. While we have begun the initial phases of this work, we have not yet finished this task.

Our focus over the remainder of the funding period will be continued development and deployment of the embedded DSP system. The goal is development of an embedded processing system that is independent from the camera. This will facilitate future sensor development as technology produces more sensitive cameras. We will also continue development/refinement of our optical models and image processing algorithms.

RESULTS

Results from our initial DSP development are encouraging. With our prototype hardware, we have successfully captured and displayed video data (240x320 pixel elements) at 60 Hz. At this frame rate, we are utilizing approximately 15% of the DSP CPU resources. We estimate we can perform at least 150 operations per pixel with the remaining headroom in DSP resources for image-processing tasks.

Figure 2 shows the results of a scattering model used to predict the shape of the laser beam. The red points illustrate the actual beam profile. The derived model for the beam profile is plotted in black. These data constitute one portion of the overall model being developed that may provide a go no-go gauge for deployment of our sensor.   Two other pieces include the model quantifying ambient light levels (Reinersman and Carder 2003) and measurements describing our system's response to light fields. ROBOT measurements in turbid waters (c = 3/m) Tampa Bay waters were successfully conducted to 2-way ranges of 12 e-folding lengths (elastic). Extrapolating indicates a maximum range of 18 e-folding lengths was possible.

Curve Fit to Fluoresence Line

$f=y0+a*exp(-0.5*abs((x-x0)/b)^c)$

Coefficient

a	257.59
b	22.60
c	1.00
x0	186.63
y0	4.13
R^2	0.99

Figure 2: A graph of the actual laser beam profile (red) and the developed model of the profile (black) when using the system off band (in fluorescence mode).
[This graph shows the approximately Gaussian profile of the laser beam (red) when imaged off band (fluoresced radiation). The black curve is our model of the beam profile.]

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. 2003). 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" and #N00014-03-1-0177 "Distribution of our CoBOP Results: IOPs and Albedo Spectra for Incorporation into Radiative Transfer Models."

Ambient light condition modeling was funded by ONR #N00014-03-1-0625 "A Hybrid Modular Optical Model To Predict 2-D and 3-D Environments in Ports and Beneath Ship Hulls for AUV Sensor-Performance Optimization in MCM Activities."

REFERENCES

Carder, K. L., D. K. Costello, H. Warrior, L. C. Langebrake, W. Hou, J. T. Patten, and E. Kaltenbacher. 2001. Ocean-Science Mission Needs: Real-Time AUV Data for Command, Control, and Model Inputs. IEEE Jour. of Ocean. Eng. 26(4):742-751.

Carder, K.L., and D.K. Costello, "Optical Effects of Large Particles", In Ocean Optics, R.W. Spinrad, K.L. Carder and M.J. Perry, Oxford University Press, New York, N.Y., pp. 243-257, 1994.

Carder, K.L., D.K. Costello, and Z.P. Lee, 2000. The Use of Unmanned Underwater Vehicles to Acquire Environmental Data in Support of Mine-Counter-Measure Operations. Fourth International Symposium on Technology and the Mine Problem, NPGS, Monterey.

Costello, D.K., W. Hou, and K.L. Carder, "Some Effects Of The Sensitivity Threshold And Spatial Resolution Of A Particle Imaging System On The Shape Of The Measured Particle Size Distribution", *SPIE Proceedings Ocean Optics XII*, 1994.

Fournier, G.R., D. Bonnier, J.L. Forand and P.W. Pace, "Range-Gated Underwater Laser Imaging System," Optical Engineering, Vol. 32, No. 9, pp. 2185-2190, September 1993.

Hou, Weilin, "Characteristics Of Large Particles And Their Effects On The Submarine Light Field", University of South Florida Dissertation, August 1997.

Kaltenbacher, E., J.T. Patten, D. English, D.K. Costello, K.L. Carder, "Development Of A Compact, Real-Time, Optical System For 3-D Mapping Of The Ocean Floor", Proceedings Of Oceanology International, May 2000.

Lee, Z., K.L. Carder, C.D. Mobley, R.G. Steward and J.S. Patch, "Hyperspectral Remote Sensing For Shallow Waters. 1. A Semianalytical Model", Applied Optics, Vol. 37, No. 27, pp. 6329-6338, September 1998.

Lee, Z., K.L. Carder, C.D. Mobley, R.G. Steward and J.S. Patch, "Hyperspectral Remote Sensing For Shallow Waters. 2. Deriving Bottom Depths And Water Properties By Optimization.", Applied Optics, Vol. 38, No. 18, pp. 3831-3843, June 1999.

Sitter Jr., D.N., and Gelbart, A., "Laser-Induced Fluorescence Imaging Of The Ocean Bottom", *Optical Engineering* Vol. 40, No. 8, pp. 1545-1553, 2001.

PUBLICATIONS

Reinersman, P. N. and K. L. Carder. (2003). Hybrid Numerical Method for Solution of the Radiative Transfer Equation in One, Two, or Three Dimensions. *Applied Optics*, [submitted, refereed]

Carder, K.L.,C.C. Liu, Z. Lee, D.C. English, J.Patten, F.R. Chen, J.E. Ivey, and C. Davis. (2003). Illumination and turbidity effects on observing facetted bottom elements with uniform Lambertian albedos. *Limnol. Oceanogr.*, 48(1), 355-363. [published, refereed].

Reinersman, P. N. and K. L. Carder, 2002, A modular, hybrid method for solving the radiative transfer equation with arbitrary geometry in 1, 2, or 3 dimensions. In *Ocean Optics XVI,* S. Ackleson and C. Trees (eds.), Office of Naval Res. CDROM, Arlington, VA, 6 p. [published]

English, D.C., K.L. Carder, W. Hou, and D.K. Costello, "Use of Unmanned Underwater Vehicles to Determine the Spatial Distribution of Reflectance and Optical Properties", *Poster in Ocean Optics XVI,* Nov 18-22, 2002.

Hou, W., K.L. Carder, D.K. Costello, and D.C. English, "Coastal Bottom Feature Classification Using 2-D and 3-D Moment Invariants", *Poster in Ocean Optics XVI,* Nov 18-22, 2002.

PATENTS

3-D Imaging System.