Development and Field Application of Laser Particle Imagers

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LONG-TERM GOAL

The long term goal is development and utilization of a suite of high-resolution, linescan-camera based imaging systems to investigate the distribution and composition of plankton and suspended particles in the marine environment. The system is designed with wide dynamic range and will ultimately be used for high speed, high resolution characterization of water column particle fields in high, medium and low latitudes. Such a system will have broad application to areas of defense and environmental interests such as ecological modeling efforts, Autonomous Ocean Sampling Networks (AOSN), and ground-truthing of satellite data.

OBJECTIVES

The project has two major objectives. The first is the development of high resolution imaging instruments for use in *in-situ* sampling of plankton and particle distribution in the upper 200 meters of the ocean. The second major objective is to test and apply the developed instrumentation to support scientific, defense, and environmental applications toward the development of biophysical models for the spatial distribution of particles and zooplankton.

APPROACH

The scientific approach for this project is to sequentially continue development and testing of the Shadowed Image Particle Profiling and Evaluation Recorder (SIPPER) *in-situ* particle imaging system, and to analyze technical and scientific results arising from its deployment. The system is designed to image zooplankton in the size range of a few tens of microns to over 1 centimeter in size. It was

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14. ABSTRACT
The long term goal is development and utilization of a suite of high-resolution, linescan-camera based imaging systems to investigate the distribution and composition of plankton and suspended particles in the marine environment. The system is designed with wide dynamic range and will ultimately be used for high speed, high resolution characterization of water column particle fields in high, medium and low latitudes. Such a system will have broad application to areas of defense and environmental interests such as ecological modeling efforts, Autonomous Ocean Sampling Networks (AOSN), and ground-truthing of satellite data.

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designed for mounting on the previously ONR supported High Resolution Sampler (HRS) [Sutton et al., 2001]. SIPPER currently consists of a pair of high-speed digital linescan cameras, and light source and optics for back illuminating and imaging the particles, and a custom high-speed data compression and storage subsystem for shipboard control, feedback, and storage. SIPPER has been continually improved incrementally as technology improvements became available (for instance the current cameras have 3 times the imaging resolution as the original ones used). Custom underwater high-speed data compression and storage electronics were developed to handle the data rates. Continuing this approach, this year we have initiated a redesign and combining of the SIPPER and MIPPER (miniature imaging volume version of SIPPER), incorporating the key components of the previous system, while refreshing and improving on its limitations. These improvements will be discussed in detail, below.

WORK COMPLETED

Sensor Development

Although we originally proposed primarily field-testing of the instrument in FY03, the realization was made that new off-the-shelf technologies could enable several significant improvements to the instrument. This would serve the ultimate engineering goal of the project to create a particle imaging device which has a wide range of resolutions, is robust, has low power requirements, is simple to use and repair and is small enough to fit on most AUVs and towed platforms. A reallocation of funds request was granted to allow these developments to proceed.

The new design is called SIPPER3, as it is the third iteration of the original SIPPER. SIPPER3 incorporates a flexible optical configuration that can be optimized either for imaging mesozooplankton-sized particles sampled in the original 100 mm square sampling tube (SIPPER configuration) or for imaging the smaller, more abundant plankton groups using a much reduced imaging area (MIPPER configuration). Additionally, the SIPPER3 electronics have been simplified, and overall size reduced by 90% compared to SIPPER2 (Figure 1). These improvements, and its simplification to a single camera system should significantly lower its final cost, promoting widespread use. Major changes being incorporated into SIPPER 3 are summarized below.

Single-Camera System
In order to reduce system cost and complexity, it was decided to make SIPPER3 a single-camera system. Most researchers have not indicated a significant interest in SIPPER2's ability to simultaneously image particles from two orthogonal directions. To accommodate those who would want a two-camera system, SIPPER3 is designed so that two separate SIPPERs can be mounted together and a synchronization signal can be sent from one SIPPER to the other to allow data alignment during post-processing.

New Image Compression Board
By using a new state-of-the-art field programmable gate array (FPGA), most of the 41 integrated circuits on SIPPER2's FPGA circuit board have been incorporated into a single, smaller chip. The flat-field correction and image compression algorithms are the same as those used successfully in SIPPER2.

Migration to a FireWire data storage system
FireWire©, also known as IEEE1394, is a high-speed serial bus that is commonly used for digital video cameras and external hard drives. This will allow us to convert the data storage system of SIPPER3

from 3 ultra-ATA hard drives and a costly controller, to a single 120 GB FireWire© hard drive. This drastically improves power consumption, the number of connectors, size, and speed. The data storage system only needs a 6-conductor cable to connect to a swappable hard drive.

Environmental Sensor Data Storage
Previously, environmental data was collected separately from SIPPPER image data and therefore had to be time-synchronized for analysis. SIPPER3 allows the data from other sensors to be embedded in the image data stream and stored together. The method of combining the data from various sensors and transferring it to SIPPER is the subject of a patent application and cannot be disclosed at this time.

SIPPER2 and SIPPER3 Size Comparison

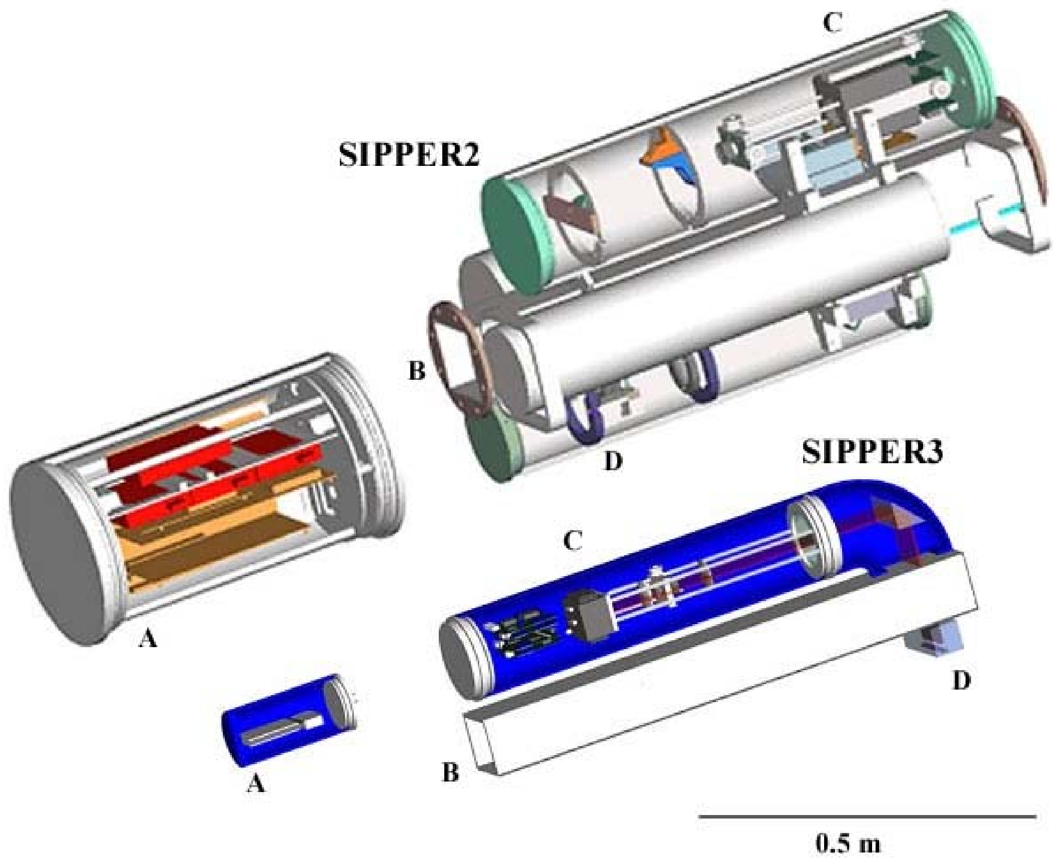

Figure 1. Size comparison of SIPPER components between SIPPER2 and SIPPER3. Components are A. Data storage, B. Sampling tube, C. Camera and optics, and D. Illumination source. [Improvements made SIPPER3 significantly smaller in size and weight than SIPPER2]

New User Interface
SIPPER3 has a flexible user interface dependent on the platform SIPPER is deployed on. The most commonly used interface is the same as SIPPER2, using an embedded web server (Lantronix X-Port) as a graphical interface that allows basic on/off control of the cameras, illumination system, and recording, as well as display text readout of some other sensors (temperature, depth, flow-rate, etc.). The second interface is a serial, text-based, menu system that simplifies control interfacing with

autonomous vehicles or moorings. It also serves as a backup interface in case of Ethernet network failure. The preferred interface that is capable of displaying real-time SIPPER imagery and sensor data in a graphical format is under development. For this, the FPGA on the Image Compression Board will collect "snapshot" sample images and send them to the GUI program on the shipboard computer to display to the operator once per second.

New Optical Design
The SIPPER3 design uses a multi-lens system that has shown less distortion in computer modeling, while allowing a shorter path length. The laws of physics limit the ratio of depth-of-field vs. resolution that is also dependent on the wavelength of light. An adjustable iris will be positioned to allow this tradeoff to be easily adjusted, although different sampling tubes will be needed to keep the center of focus in the middle of the tube. This feature allows SIPPER3 to fit the requirements of SIPPER and MIPPER, interchangeably.

A new illumination system uses high-intensity LEDs to reduce size, complexity, and power consumption, yet increase reliability. LEDs are available in a range of colors, allowing us to select a short wavelength (504nm cyan) to achieve better resolution than with the 635nm laser illumination used in prior SIPPER versions.

New Instrument Layout and Assembly
Enabled by the reduction in the size of the SIPPER3 image compression and data storage electronics, we chose to house both boards in the same pressure vessel as the camera and imaging optics, to reduce the complexity (and failure potential) of the external electrical connectors. The reduced optical path length eliminates the need for the folded light path used in SIPPER1 and SIPPER2. The folded light path required a window and mirror-mounting block to be welded into the tube. This made it difficult to install and adjust the optics. These improvements will save weeks of assembly, adjustment and calibration time.

Field Application

SIPPER2 was deployed on the High Resolution Sampler [Sutton et al., 2001] for a planned ten-day cruise in the northeast Gulf of Mexico on July 10, 2003. Our goal was to use SIPPER to investigate the horizontal and vertical distribution patterns of oceanic mesozooplankton and other particles in the presence of a narrow band of Mississippi River plume water that had been advected offshore. This cruise ended prematurely when the custom made block used to deploy the HRS off the ship U-frame catastrophically failed during the first day of deployments. Approximately 100 minutes of new SIPPER grayscale data was collected before the mechanical failure. No instruments were damaged. A new block has been ordered and shiptime has been rescheduled.

RESULTS

Analysis of SIPPER data collected in the northeast Gulf of Mexico during the summer of 2000 indicate that SIPPER can provide significantly more accurate estimates of mesozooplankton abundance, biomass and composition than either an Optical Plankton Counter (OPC) or plankton nets [Remsen et al., in press]. This study required manual classification of over 175,000 SIPPER images into 14 plankton and particle classes.

As this is both a labor intensive and expensive effort, much of this years work has been spent on a parallel effort with investigators from another ONR funded project (Award # N00014-02-0266) to develop an automated image classification software package to use with SIPPER. Our contribution has entailed extraction of binary and grayscale images from multiple collected SIPPER deployments, and classification of the images into identifiable groups. Over 100,000 images have been manually sorted into over 50 plankton and particle classes and grouped into experimental training sets. The sorted images have been used as initial validation data for classification models that are being tested in lab and field use.

The new extraction and classification software package was tested at sea and performed well. Images could be extracted, classified and written to disk almost as fast as the data was generated. For example, an 8-minute SIPPER run at 20 meters had 12,000 particle images extracted and classified in 14 minutes.

The transition to grayscale imaging has allowed for significant improvement to our automated classification effort. Preliminary experiments indicate that addition of grayscale features has improved the overall classification model accuracy by over 10%.

IMPACT/APPLICATIONS

This project represents a directed effort to develop, build and deploy imaging systems that can characterize the oceanic particle spectrum in sizes from centimeters to micrometers and be deployed on AUVs, ROVs and towed or moored sampling systems. As such, it is a part of the larger goals of much ONR-directed research to create systems that can efficiently monitor oceanic conditions with a minimum of temporal and spatial degradation and without the use of expensive and time-consuming research vehicles. Such information would then become a major input to forecasting (or 'nowcasting') significant conditions in the coastal ocean.

RELATED PROJECTS

Development of software enabling automated classification of SIPPER images is being funded through ONR award # N00014-02-1-0266. The SIPPER web site is at http://marine.usf.edu/sipper.

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