Automated Control of a Fleet of Slocum Gliders Within an Operational Coastal Observatory

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Abstract

Rutgers University, Webb Research, Dinkum Software, Wetlabs, and Mote Marine Lab have been collaborating on the development and deployment of a fleet of Slocum Gliders to continuously patrol the coastal oceans. The Gliders are AUVs that move up and down in the water column in a saw-toothed pattern by changing their buoyancy. Presently, during a deployment, humans must look at the data, determine if a change in the sampling protocol is indicated by the data and if so, upload a new mission to the Glider.

Rutgers has been focusing on the development and testing of the software to automate the control of the Gliders. Using Agent Oriented programming, the goal of the software is to assimilate data received by the Command Center from the Gliders and other Agents, such as CODAR and satellites, and generate new missions for the Glider fleet. The software is being developed on a Linux system. The ability of the Command Center computer to automatically analyze data from a Glider or Gliders and recognize thermoclines and haloclines were the first pieces of the control software to be developed. Testing of the thermocline software has been completed using both hand generated data and real data collected in January 2003 from the Gulf of Mexico.

New sensors are being added for applications in the New York Bight and on the West Coast Florida Shelf.

I. INTRODUCTION


Fig. 1: The SLOCUM

The Slocum Autonomous Underwater Gliding Vehicle (AUGV) (Fig. 1), designed and built by Webb Research Corporation* (Falmouth, MA), is an integrated instrument platform designed to operate in the coastal oceans. The glider travels by diving and climbing in a saw tooth pattern to a predetermined set of waypoints by adjusting its buoyancy. This motion results in a low cost, quiet, highly adaptable autonomous underwater vehicle with a very low power requirement. Gliders are capable of communicating with a shore or boat based computer via high frequency radio transmission and/or satellite communication link. The glider has an average forward velocity of 1.0 knot. The estimated range of operation is 1500 km and mission duration of up to 30 days. Our goal is to develop an intelligent fleet of coastal Slocum Gliders that provide maps of the physics, bio-optics and biology of remote coastal waterways. These systems will become an operational asset for the proposed Ocean.US Integrated Ocean Observing System (IOOS) and the NSF Ocean Observing Initiative (OOI).

II. THE SLOCUM VEHICLE

Each 2 meter long glider is equipped with a Sea-Bird Electronics non-pumped, low drag conductivity, temperature and depth (CTD) sensor. Additionally, a 9-14KHz transducer used for a pinger or acoustic modem and a 200KHz transducer used by the altimeter to provide bottom bathymetry measurements are located in the nose cone. The rest of the glider is reserved for glider mechanics, battery storage and communication

*This work was sponsored by National Science Foundation, Office of Naval Research, National Ocean Partnership Program and National Oceanic and Atmospheric Administration.

equipment except for a small section, devoted exclusively to integration of customized scientific payload. The vehicle can be fitted with a suite of miniaturized physical and bio-optical instruments to accurately characterize sound and light transmission properties (i.e. sound speed and diver visibility).

III. COMMUNICATION and LOCATION EQUIPMENT

Located in the tail of each glider are two bi-directional communication links, one for RF the other for satellite, and one unidirectional communication link for ARGOS (Fig. 2). The high frequency radio (RF) communication link (Freewave Technologies) allows for high speed (115200 bps), line of sight, data transmission. A strategically placed repeater (high on coastal towers or on the underside of survey aircrafts) can increase the RF communication distance to up to 60 miles, depending on sea state. The satellite telephone link

Fig. 2: Slocum tail fin, which houses the GPS/Iridium, ARGOS and R/F modem antennas.

(Iridium Satellite LLC) provides global communication coverage and allows for the Glider to be deployed from over the horizon to travel into the area of interest. The Iridium antenna has had a 98% success rate. Iridium data transfer rates are about 50 times slower than radio modem and costs are still being negotiated. Costs range from $0.10/min for DOD (via NRL and ONR), $0.20/min from Omnet, and over $1.00/min for commercial access. The present science data files produced can be transmitted to shore via radio modem in about 12 seconds. The same file transferred via Iridium takes approximately 10 minutes. Further compaction of files is possible, with the final size dictated by transfer times and affordable costs. For West Florida shelf applications, we envision hourly Iridium transfers from each Glider for short data files, augmented by overflights on aircraft of opportunity to download larger files from the AUV fleet. The entire data set will be stored on-board the Glider. The ARGOS transmitter broadcasts the glider's position in case emergency retrieval becomes necessary.

The GPS which tracks all visible GPS satellites while on the surface, providing very accurate positioning data, shares the Iridium antenna. Underwater, the glider keeps track of its bearing, pitch and roll using an attitude sensor and dead reckons to its next location using its' bearing and approximate horizontal speed.

IV. GLIDER CONTROL SOFTWARE

Recent research has focused on the design and implementation of a centralized control system to coordinate the movement of a fleet of gliders (Fig. 3)

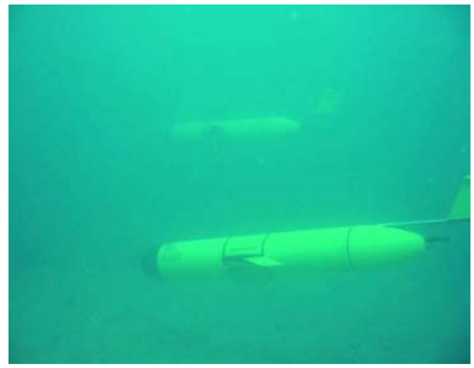

Fig. 3: Multiple glider deployment

based on data available from the fleet or other scientific systems, including CODAR sites and Satellite Ocean Color or SST imagery. Goals for a robust Glider Mission Control Center are:

1) The ability to communicate with multiple gliders simultaneously
2) Process incoming files to determine the presence or absence of significant physical and/or bio-optical features
3) Make changes to current mission files to optimize tracking of the feature(s) by one or more of glider agents
4) Notify the scientist or fleet commander of a change in mission agenda, an encountered problem or to update the status of the current mission
5) Synthesize data from other sources (satellite ocean color, sea surface temperature, CODAR surface wave fields, etc.) for integration of observational results into the mission decision-making process.

Implementation of the Glider Mission Control Center is based on the same Agent Oriented programming used by NASA to construct exploring rovers and intelligent machines, which are self-aware, self-controlled and self-operated robots. One example is the Deep Space 1 spacecraft, which most recently self- navigated through the tail of comet Borrelly. Individual gliders may also be manually deployed with a defined mission such as a sweep through prospective shipping lanes, or other areas of particular interest to the mine countermeasures commander.

V. DATA PRODUCTS - OCEAN PHYSICS

The Sea-Bird CTD provides continuous measurements of water temperature, conductivity and depth (Fig. 4). These parameters are used to derive sound speed profiles and water densities, which are key parameters in assessing the ability to acoustically locate subsurface mine fields.

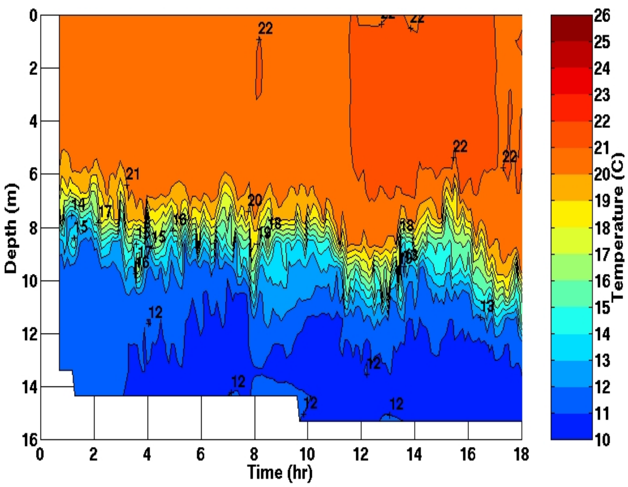

Fig. 4: Typical temperature dataset generated from one segment of a glider mission.

In addition to these physical parameters, a measure of depth averaged currents and surface currents can be calculated (Fig. 5). In summary, the depth averaged

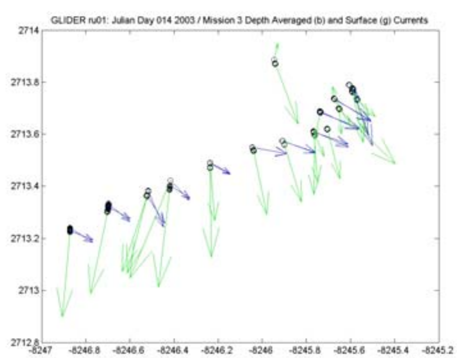

Fig 5: Display of depth averaged (blue) and surface (green) currents from Gulf of Mexico January 14, 2003.

current is calculated by determining the difference between the presumed (dead reckoned) location and the actual (GPS) location and dividing by the time spent underwater. Comparisons of these calculated currents to ADCPs show excellent agreement (Fig. 6).

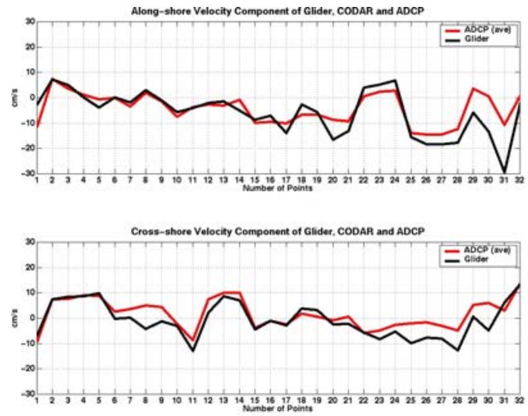

Fig. 6: Along- and cross-shore currents derived from the expected and actual location of the Glider during its July 13-22, 2000 mission compared with moored ADCP data.

Surface water currents and winds are the primary factors influencing vertical mixing in the oceans and this mixing heavily influences water clarity and, by extension, diver visibility. While on the surface in between data transmissions, the glider is obtaining GPS positions. This time spent on the surface allows for the determination of both surface water currents and wind fields. A measure of the strength and direction of the surface current can be obtained by dividing the change in position while on the surface by the time spent on the surface. Surface wind direction can also be measured since the glider always faces nose-into-the-wind. With this in mind, the wind direction is 180º opposite the glider's heading as measured by the attitude sensor.

Waterway bathymetry is obtained using the depth measurements from the CTD in conjunction with the altimeter measurements. As the glider descends, altimeter hits are logged. From these hits, a mean

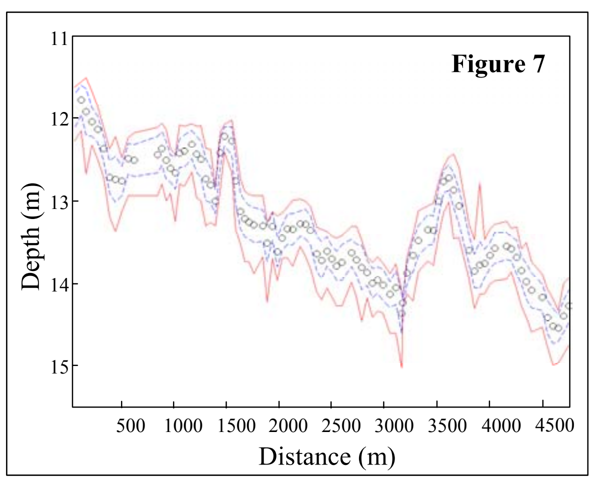

Fig. 7: Bathymetry

water depth can be calculated (black circles) along with measurements of statistical accuracy (blue lines). The red lines represent the maximum and minimum altimeter hits recorded on each dive (Fig. 7).

VI. DATA PRODUCTS – OCEAN OPTICS

In order to provide measurements of water clarity, biological and geological particle load and light transmission in coastal ocean environments, integration of a suite of bio-optical sensors into the science payload bay is currently underway. Specifically, a HOBILabs Hydroscat-2 (Fig. 8), which measures backscattered light at two wavelengths, B_b676 (red) and B_b470(blue), and chlorophyll fluorescence at B_b676 (Fig. 9). These measurements are used to provide an estimate of particle load due to the presence of biotic or abiotic particles, which provides insight into wavelength specific light transmission through the water.

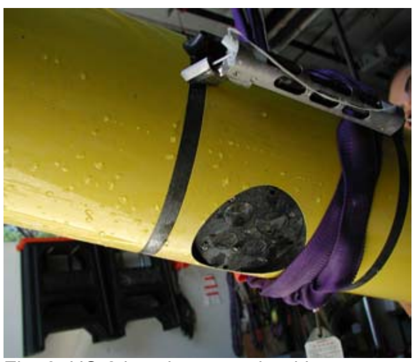

Fig. 8: HS-2 in science payload bay

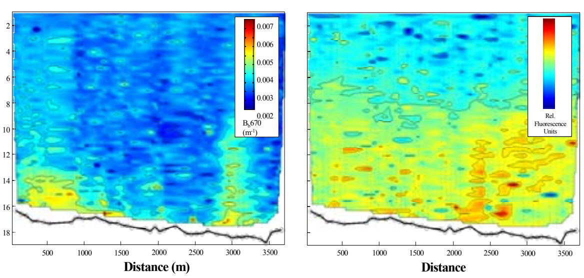

Fig. 9: Optical backscatter and chlorophyll a fluorescence with bathymetry Gulf of Mexico January 2003.

Beam attenuation (beam c) is a key optical variable that has shown utility in predicting the upward and downward propagation of light through the water column. The problem is that c-measurements generally require a significant (0.25-0.5 meters) distance between the light source and the detector (defined as the path length) (Fig. 10), so c-meters tend to be big. In order to be miniaturized, engineers at (WETLabs, Inc.) have developed a sensor (Scattering Attenuation Meter, SAM) that measures scattering at the same angle over 2 different path lengths and then uses these measurements to calculate beam c. The SAM prototype is built and has been laboratory calibrated. The sensor is to be mounted in the science payload bay of the Slocum Glider along with absorption and fluorometry sensors. This will result in a compact integrated sensor package that will provide simultaneous measurements of multiple optical properties and will improve spatial and temporal resolution of diver visibility profiles necessary for successful counter mine warfare operations.

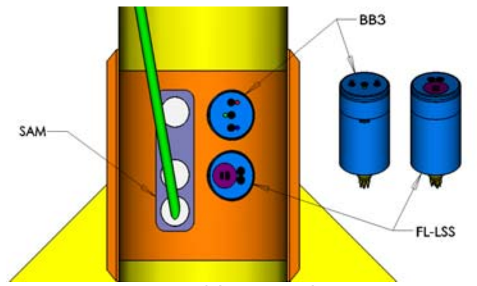

Fig. 10: Integration of SAM into Slocum payload bay.

Additionally the National Science Foundation awarded funds to Mote Marine Lab, Webb Inc., RU COOL and Cal-Poly to miniaturize a capillary waveguide spectrometer that has been used to track *K. brevis* in the GOMx [1] [2]. This system provides hyperspectral absorption measurements (1.2 nm resolution) allowing a range of pattern recognition algorithms to be applied. *K. brevis* algorithms have been developed and validated in natural populations [3] [4] [5]. The miniaturized waveguide system has been developed and has been tested onboard a Glider in the Mid-Atlantic Bight (Fig. 11).

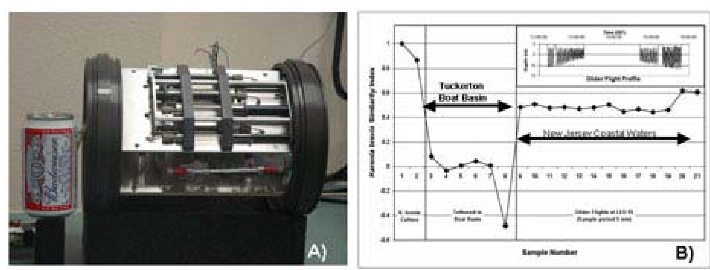

Fig. 11. A) A miniaturized capillary waveguide red-tide detector system that measures hyperspectral absorption. Efforts by the engineers successfully reduced the size of the system to that of a 6-pack. The system has been integrated and flown in a Slocum Glider in May 2003. B) Data collected by a capillary waveguide on a Glider. The data flight track in the Mid-Atlantic Bight is shown in the upper inset. The hyperspectral data was used to calculate a similarity index for *K. brevis*. *K. brevis* cultures has high SI indexes, as expected, and data collected in the Rutgers boat basin and out on shelf did resemble *K. brevis*. Again this is expected as *K. brevis* is not present in these waters. This illustrates that SI indexes can now be measured on Long duration Gliders.

VII. SUMMARY OF BENEFITS

Autonomous Underwater Gliders are a new emerging technology that will complement ongoing efforts to build global and coastal ocean observatories. The Slocum Electric Glider is specifically designed for coastal applications, providing critical subsurface information between spatial surface maps acquired from visible and thermal satellite imagers and shore-based HF radar networks. New bio-optical sensors previously deployed on shipboard profilers are being miniaturized to fit in a standard Glider payload bay. To take full advantage of this new platform and sensing systems, it is envisioned that Gliders will be operated as collaborative fleets. A Glider Control Center with decision making capabilities of detecting and tracking thermoclines and fronts is being constructed and tested in the New York Bight and the West Coast of Florida.

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