Wave Glider® ASV Ocean Acidification Sensor Integration for Marine Management Applications

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ABSTRACT

Monterey Bay Aquarium Research Institute's (MBARI) evolving fleet of ocean observing systems has made it possible to collect information and data about a wide variety of ocean parameters, enabling researchers to better understand marine ecosystems. In collaboration with Liquid Robotics Inc, the designer of the Wave Glider autonomous surface vehicle (ASV), MBARI is adding a new capability to its suite of ocean observing tools. This new technology will augment MBARI research programs that use satellites, ships, moorings, drifters, autonomous underwater vehicles (AUVs) and remotely operated vehicles (ROVs) to improve data collection of temporally and spatially variable oceanographic features. The Wave Glider ASV derives its propulsion from wave energy, while sensors and communications are powered through the use of two solar panels and batteries, enabling it to remain at sea indefinitely. Wave Gliders are remotely controlled via real-time Iridium burst communications, which also permit real-time data telemetry. MBARI has developed Ocean Acidification (OA) moorings

to continuously monitor the chemical and physical changes occurring in the ocean as a result of increased levels of atmospheric carbon dioxide (CO_2). The OA moorings provide good temporal observations, however being anchored to the seafloor spatially restricts them. During the summer of 2011 the ocean acidification sensor suite designed for moorings was integrated into a Wave Glider ASV to increase both temporal and spatial ocean observation capabilities. The OA sensor package enables the measurement of parameters essential to better understanding the changing acidity of the ocean, specifically pCO_2, pH, oxygen, salinity and temperature. The Wave Glider will also be equipped with a meteorological sensor that will measure air temperature, air pressure, and wind speed and direction. The OA sensor integration into a Wave Glider was part of MBARI's 2011 summer internship program. The project involved designing a new layout for the OA sensors within a Wave Glider aft payload drybox and the addition of a CO_2 standard tank. In the future these ASVs will provide platforms for additional surface and subsurface instrumentation, particularly with MBARI's upcoming Controlled, Agile, and Novel, Observing Network (CANON) projects.

Image 1: A Wave Glider floating next to MBARI Mooring M1 in Monterey Bay, CA.
Photo from Liquid Robotics website

PROJECT GOALS

The goal of this 2011 MBARI internship project was to integrate MBARI's OA sensor suite currently being used in MBARIs OA moorings into the aft payload of a Wave

Glider autonomous surface vessel. In addition to this primary goal, the summer project was meant to provide hands on experience in what it takes to complete the sensor integration of an ASV used for ocean monitoring.

The OA Wave Glider integration project was broken down into four separate jobs (shown in Image 2 below). In order for a Wave Glider to be deployed with an OA sensor package, all of these steps need to be completed. Over the course of ten weeks, the valve block was designed and integrated into the Wave Glider lid, however the air block valve is currently being designed at MBARI. Job 2 (the primary objective of this summers project) was designed and built, while Jobs 3 and 4 still will be completed in the near future by MBARI and Liquid Robotics engineers.

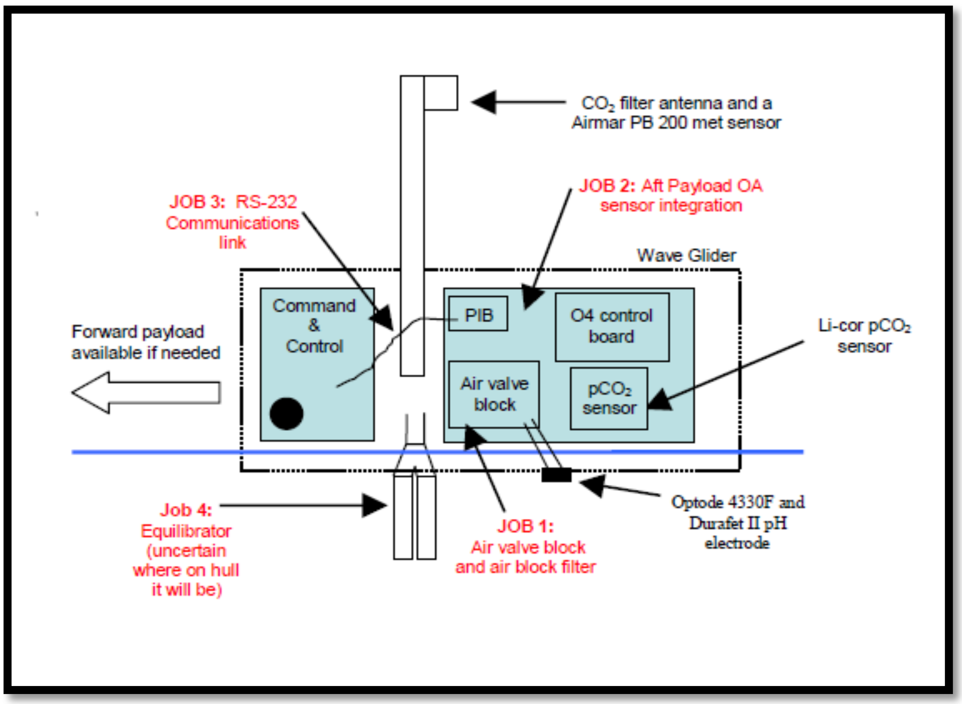

Image 2: Diagram of the necessary steps needed to take place to complete Wave Glider OA sensor integration. Jobs 1-3 were completed while Job 4 still remain to be finished

INTRODUCTION

An increase in the concentration of anthropogenic CO_2 in the atmosphere since the industrial revolution is currently having significant impacts on the earth's biosphere. Current atmospheric CO_2 levels are around 390ppm and are rising at ~0.5% per year, which is ~100 times faster then any change in the last 650,000 years (Guinotte and Fabry

2008). The ocean has always acted as a natural carbon sink for CO_2 and since the 1800s the ocean has absorbed approximately one-third of all atmospheric CO_2 (Sabine et al., 2004). To date researchers are still attempting to understand the impacts an increasingly acidified ocean will have throughout the earth's biosphere, however this has proved difficult due to the constant change of the ocean. New technologies are needed to continuously monitor the marine ecosystem in order to better understand the role physical, chemical and biological processes play in the acidification process (Doney, 2008). ASV technology like the Wave Glider can provide persistent documentation of these natural processes, which will produce data that can shed light onto the impacts ocean acidification is having on the marine environment.

Currently MBARI's ocean observing systems are somewhat limited both spatially and temporally. Moored buoys are capable of measuring a variety of parameters continuously for long periods of time, but buoys are limited by being anchored to the sea floor. Autonomous underwater vessels (AUVs) like the *Dorado* AUV and the *Tethys* AUV are both exceptional research vessels for documenting areas remotely, however this technology is restricted by battery life allowing these vessels to remain at sea autonomously for short periods of time. Current MBARI remotely operated vehicles (ROV) like the *Ventana ROV* and the *Doc Ricketts* ROV are valuable vehicles for collecting samples and capturing images at great depths, however they are limited both temporally and spatially by being tethered to a ship and are only deployed during costly cruises. Through the addition of a Wave Glider to MBARI's existing Ocean Observation systems, it is possible to add a persistent monitoring device that can continuously measure a variety of physical and chemical parameters.

In an effort to monitor such changes occurring in the ocean as a result of increased levels of atmospheric CO_2, MBARI has developed Ocean Acidification (OA) moorings to continuously monitor a variety of relevant parameters in the ocean. While these moorings are useful for observing the ocean continuously on a temporal scale, they are spatially restricted by being anchored to the seafloor. This summer an ocean acidification sensor suite, originally designed for MBARI's OA moorings, was integrated into a Wave Glider to increase both the temporal and spatial capabilities of ocean observation systems. The OA sensor package enables the measurement of parameters essential to better understanding the changing acidity of the ocean, specifically pCO_2, pH, oxygen, salinity and temperature. The Wave Glider will also be equipped with a meteorological sensor suite that will measure air temperature, air pressure, and wind speed and direction.

Aside from being used for OA research, the Wave Glider will also serve as a platform that can be utilized by other MBARI initiatives currently taking place. For example the Wave Glider will immediately contribute to MBARI's Controlled, Agile and Novel Observing Network (CANON) experiments by providing additional support for current observing tools already being used. During the October 2010 CANON experiment that aimed to determine the role harmful phytoplankton blooms have on the health of the ocean ecosystem, a Wave Glider was included as part of the observing system infrastructure. The Wave Glider successfully provided support to other ocean observing technologies being used during the experiment by providing persistent support throughout the month long experiment. By remaining deployed throughout the experiment the Wave Glider provided data during periods when other technologies were not being used. Specifically, over the weekend when AUVs and ROVs were not deployed, the Wave Glider continuously collected data that was used on Monday to direct the other vessels. This saved time searching for interesting processes occurring in the bay and enabled more efficient data collection and exploration.

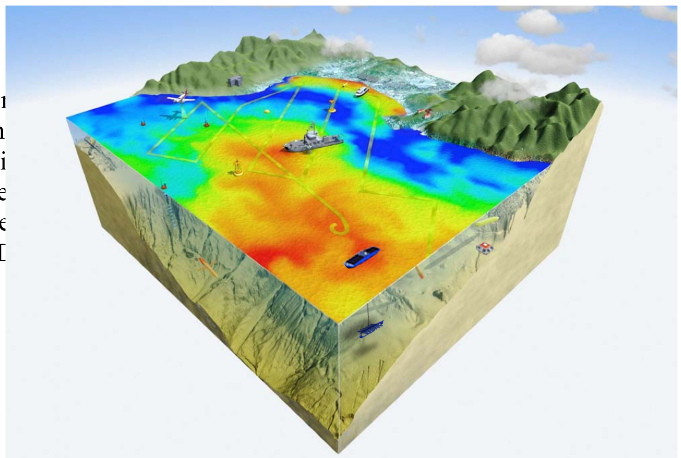

Image 3: MBARIs Co
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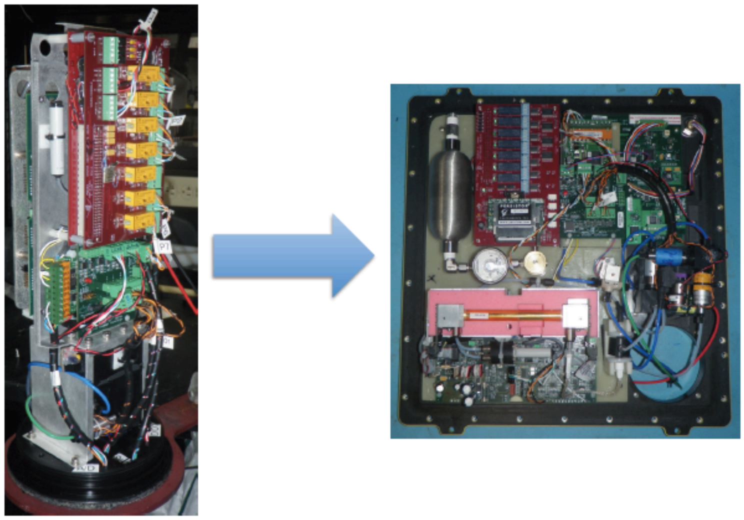


Image 4: On the left is the internal OA mooring electronics in a cylindrical design. The OASIS board is the on front with Licor on back. On the right is the internal electronics on the Wave Glider aft payload lid.

METHODS

MBARI received the aft payload dry box and Command and Control (C & C) drybox from Liquid Robotics as part of the Wave Glider start up kit funded by The Google Tides Foundation. The first step in the integration process was to determine if the OA mooring electronics, shown in a cylindrical shape above in image 4, could be redesigned to fit into a 15.5 x 14.5 inch Wave Glider drybox. The layout and design was first created in Solid Works 11.0 to ensure that all the necessary components would fit within the limited space. MBARI received the aft drybox, as opposed to the forward drybox, because it is Liquid Robotics preference to fill the aft payload first due to weight limitations. Once a layout was approved, a fiberglass mounting plate was designed and mounted to the Wave Glider lid. The different instruments and electronics were then mounted to the mounting board.

Once mounted the different electronics were wired to the OASIS board. Some minor plumbing between the valve block and the Licor CO_2 Gas Analyzer sensor was also designed and plumbed. This plumbing was necessary to enable the external measurement of pCO_2 to take place within the drybox, which will require drawing in air from an equilibrator that is used to bubble seawater to form a gas that is then measured by the Licor Gas Analyzer. This determines the parts per million of dissolved CO_2 that is currently present at that location in the ocean. A CO_2 standard tank was added to the

Wave Glider OA sensor package and has resulted in the need for an additional valve. Additional software engineering will need to take place because all of the sensors integrated on the Wave Glider will be connected to MBARI's OASIS controller board. The OASIS controller is used as a multisensory interface that communicate through the Wave Glider Personal Integration Board (PIB), which sends all of the sensor data collected by the OASIS board to the Wave Glider C & C through an RS-232 connection (Liquid Robotics, 2011b). The Wave Glider C&C will likely request data from the OASIS controller, which will dump data at set intervals, most likely a few times per day. This data is then sent through Iridium Burst Satellite communications, which can be received in real-time on shore from any computer with an Internet connection through the Wave Glider Management System (MGMS).

Wave Glider has set up an account for MBARI on the WGMS website, which is accessed through an Internet connection. MBARI has their own webpage that is used to manage missions during deployment. This interface allows for easy communication of the Wave Glider from multiple users in different locations and enables real time control of the vehicle.

Prior to deployment the Wave Glider communications can be configured through the use of a local Xbee®-Pro2.4 GHz 802.15.4 modem when operations range less then 100ft (Liquid Robotics, 2011c). This communication is free and is typically used during systems configurations and short distance deployment. For mission deployment an Iridium® 9601or 9522B modem Short Burst Data (SBD) protocol is used for real-time data communication (Liquid Robotics, 2011a). During the summer internship project, communications with the Wave Glider C&C through the Xbee modem was established. Communications through Iridium satellite was also achieved through the WGMS, however controls were limited because communications between the OASIS board and the C&C has yet to be established.

MATERIALS

Sensor Platform:

The Wave Glider ASV provides a platform for data collection that is novel in relying only on wave power for propulsion. The Wave Glider is made of three primary components, the surface float, the underwater glider, and a 7-meter tether called the umbilical cord. The glider is used to harvest energy from waves to provide forward propulsion so that the ASV is self-propelled, moving the Wave Glider between 0.4kts - 2.0kts depending on ocean conditions (Liquid Robotics, 2011a). This allows the float to collect data at a lower cost than research vessels, especially in remote ocean locations and rough sea conditions where Wave Gliders function very well (McGillivary and Hine, 2007; Wilcox, et al., 2009; Wiggins, et al., 2010). Atop the surface float, the Wave Glider is equipped with two solar panels that are capable of producing a maximum of 80 Watt-hours of energy to power on board electronics and payloads. Energy produced by the solar panels is stored in Lithium-ion rechargeable batteries that are capable of storing 665-Watt hours. The Wave Glider C & C requires 1.5 Watts of continuous power, while the batteries can provide the three payloads a maximum of 3A / 13.2 V. The glider float is capable of remaining at sea for longer than one year and has a brief submergence rating to 2 meters (Liquid Robotics, 2011a).

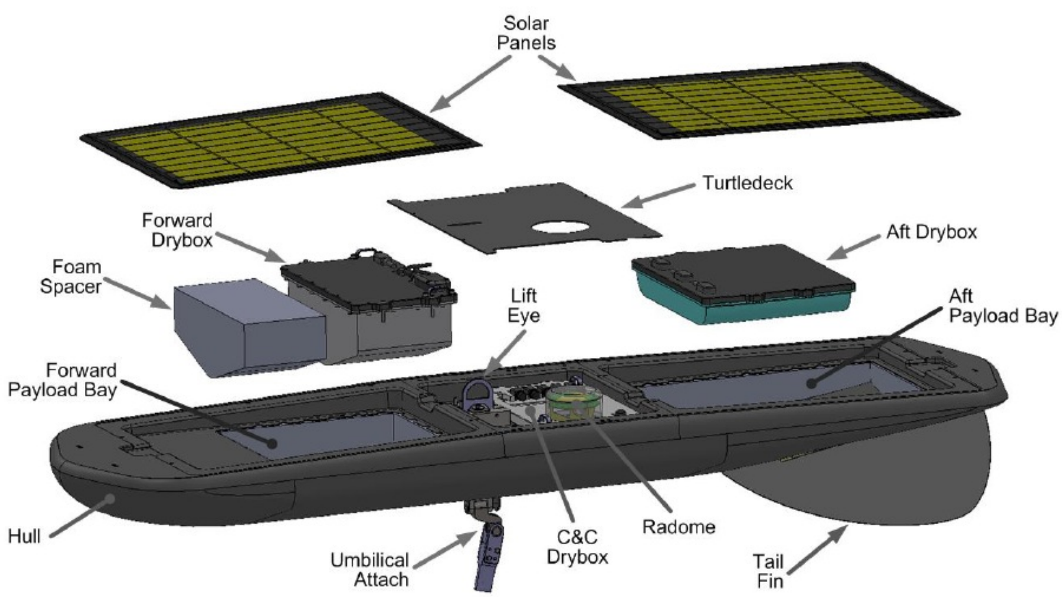
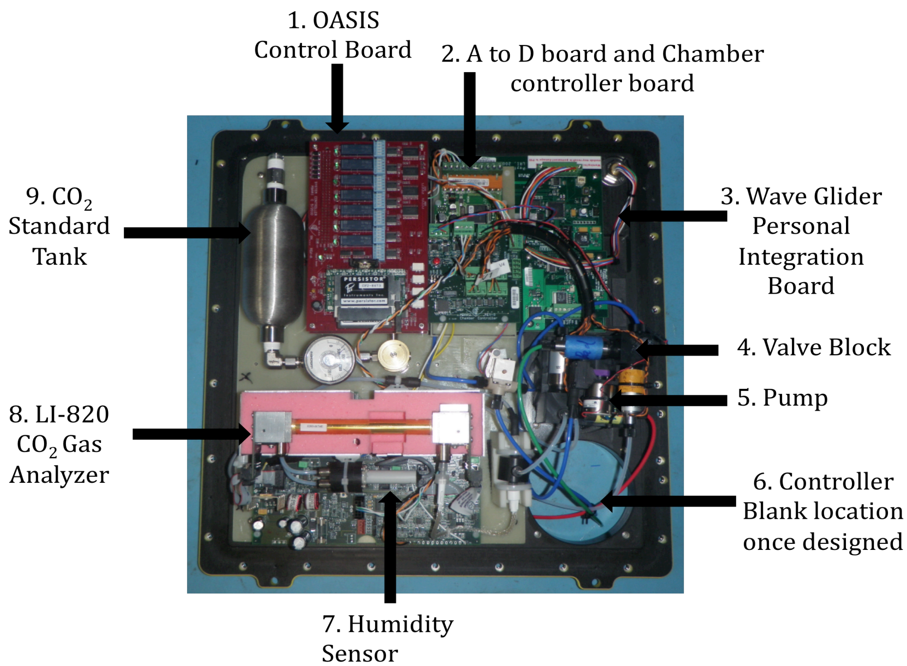


Image 5: Basic Wave Glider components. Currently MBARI has the C&C Drybox and the Aft Drybox. Image from Liquid Robotics.

This summer MBARI received funds through the Google Tides Foundation to purchase the Wave Glider C&C and the aft drybox (shown in Image 5 above). While these two components make up only a small portion of the entire Wave Glider, these parts are key to successfully integrating MBARI's OA sensor suite. Once funding for the complete Wave Glider has been established, this integration system could almost immediately be tested within Monterey Bay. Liquid Robotics is currently designing a fairing to mount to the rear of the hull. The pH sensor, O_2 sensor and MBARI's equilibrator will be mounted on the hull, behind the C&C drybox and in front of the Tail Fin. In an effort to ensure the near future completion of this project, Liquid Robotics and MBARIs Biological Ocean Group (BOG) will have weekly meetings for ten weeks starting August 7, 2011.

Image 6: Photo of Wave Glider internal drybox electronics



Internal Aft Drybox Electronics:

1. OASIS Controller Board:

The Ocean Acquisition System for Interdisciplinary Systems (OASIS) was designed by MBARI to enable researchers to investigate oceanic and atmospheric variability. Historically there has been an insufficient amount of biological and chemical time series, in part due to a lack of instrumentation but also in part to the absence of a controller platform that could easily be used by a variety of different instruments (Chavez et al., 2003). Today new instruments are being developed at a rapid rate, which means it is crucial to have a controller that is capable of adapting to the latest technologies. The OASIS controller was designed to interface with a wide variety components including A to D Board, Chamber Controller (digital I/O), and a variety of scientific instrumentation including the Licor CO_2 via RS-232 and RS-485 connections. OASIS is a general-purpose controller that collects data from scientific instrumentation through multiple interfaces and telemeters into real-time (Chavez et al., 2003). Over the past two decades the OASIS controller has progressed from the original design to its current design as the OASIS 4 control board. While the OASIS 4 board was designed for the Benthic Respirometer Upgrade led by Jim Barry, the MBARI Biological Oceanography Group has deployed two OASIS 4 controllers within two OA moorings positioned along the northern coast of Monterey Bay, CA, which are making continuous observations of physical and chemical properties. The OA moorings measure pCO_2, pH, salinity, oxygen saturation, and meteorological data (air temperature, air pressure, wind speed, and wind direction). The OASIS controller allows for multiple sensors to be integrated into one system, which provides high-resolution measurements of multiple parameters within one system. The OASIS controller interface has been integrated into a Wave Glider ASV system in order to expand the capabilities of the MBARI ocean observing system by increasing temporal and spatial observations.

2. A to D board:

This is an electronic device that converts analog voltage (typically 0-5 V) to a digital representation that can be manipulated and recorded by computers. This board converts analog voltages received from the OA sensors into a readable language.

Chamber Controller:

Oasis controller board controls the chamber controller which has relays that turns on and off the different devices that make up the OA sensor suite.

3. Wave Glider Personal Integration Board (PIB):

The PIB board comes with the Wave Glider and runs on MicroC/OS, an embedded multitasking operating system, which communicates with the C&C and the other payload via the RS-232 line (Liquid Robotics, 2011b). This board is essentially what MBARI's OASIS board uses to send data to the Wave Glider C &C. The PIB and OASIS are connected by a RS-232. This connection leaves the drybox through a bulkhead and is directly connected to the C&C. Establishing this communications ensures that data collected from the OA sensors is sent to the C&C, which is then sent through the Iridium satellites to shore.

4. Valve Block:

The valve block switches through the different plumbing tubes and is essential for the sampling of CO_2. The valve block moves air to and from the equilibrator and vents air and takes in air from atop the mast. This system moves through a variety of modes that are used for different purposes during the pCO_2 sampling process. There are five different modes: equilibrator, zero, air, standard sample or rest mode. The valve block that has been used for this project is the same valve block that was designed for the OA mooring, however it had to be slightly modified to fit into the Wave Glider aft drybox. An additional valve was added to the OA system because of the addition of the CO_2 standard tank. A new valve block was designed in Solid Works for the additional standard mode, although this valve block was not used. Instead an additional valve (shown in the center of Image 6) was attached directly to the standard tank and then plumbed into the existing valve block.

The base of the valve block is hollowed out and filled with soda lime, a mixture of chemicals in granular form used to remove moisture from the sampled air and to prevent CO_2 retention in the sensor.

5. Pump:

A KNF micro diaphragm pump has been mounted to the top of the valve block and is used to pump the air through the different valves. The pump has a 12 V DC motor that is run at 9 V through the use of a voltage converter.

6. Connector Block:

This connection is critical to the integration process because it connects plumbing and wiring from the interior of the drybox to external sensors and components. This part will be designed and machined by Liquid Robotics engineers according to MBARI specifications.

7. Humidifier:

Two humidifier sensors are mounted within the drybox to measure whether moisture has entered the drybox or not. The sensors are used to measure relative humidity and are manufactured to by Measurement Specialties Inc.

8. LI-820 CO_2 Gas Analyzer (see *Sensors* below).

9. CO_2 standard tank:

The CO_2 standard tank is used to ensure that the data being collected is consistent and provides an additional reading for data calibration. The tank is filled with a level of CO_2 that is typically found in the ocean (around 380ppm) and is run through the system occasionally during one of the sampling modes (equilibrator mode, air mode, zero mode, standard mode and rest mode). The zero mode, like the standard mode, is used to ensure there isn't a jump in levels of CO_2 being recorded. With the addition of a standard mode within this system it is possible to recognize if the system is flawed in real-time and allows for greater confidence in the data collected.

Sensors

LI-820 CO_2 GAS ANALYZER:

Designed by LI-COR Biosciences, the LI-820 is an absolute, non-dispersive, infrared (NDIR) gas analyzer based upon a single path, duel wavelength, infrared detection subsystem. The Licor measures the wavelength of CO_2 gas in order to determine how much dissolved CO_2 is present in the surface sea water. The LI-820 requires an input voltage of 12-30 VDC and the power supply must be able to provide a maximum current drain of 1.2 Amps (at 12 VDC). Once warmed up, the instrument will draw about 0.3A with the heaters on.

Durafet II pH electrode:

The Honeywell Durafet II pH electrode incorporates a solid-state, ion-sensitive field-effect transistor (ISFET) sensing element that provides fast response time. The electrode is fully submersible and has a great sensor stability that minimizes the need for frequent calibrations. The large surface area of the reference junction resists fouling and maintains reliable low-impedance contact. Two lithium batteries will enable 6 months of monitoring. This pH electrode has already been used in a variety of application at MBARI, however it has yet to be mounted on the hull of an ASV.

Wet Labs Eco Puck:

The Wave Glider will have a Wet Labs Eco Puck fluorometer mounted on the hull of the float. The ECO (Environmental Characterization Optics) Puck is designed specifically for applications that require limited space and power requirements making it ideal for Wave Glider operations. Using an ultraviolet light to excite molecules that emit light at a lower energy, the ECO puck is capable of measuring the fluorescence of seawater. The ECO puck has an 80mA power requirement. Through the use of a fluorometer it is possible to fluorescence of sampled seawater. This is helpful in identifying an increase in phytoplankton growth, which is useful in identifying biological changes in the marine environment.

Seabird Payload Glider CTD (GPCTD):

Also mounted on the hull of the Wave Glider will be a CTD to measure conductivity, temperature and pressure. The GPCTD uses a small pump that allows for better measurements and reduces the risk of fouling. Liquid Robotics has plans to integrate the GPCTD to the base of the float, near the pH electrode.

DISSOLVED OXYGEN (DO) SENSOR SBE 43:

This oxygen sensor measures the oxygen content of seawater and has already been integrated and mounted directly to the Seabird GPCTD.

AIRMAR PB-200:

The Airmar PB-200 is a meteorological sensor that has been integrated with the Wave Glider C & C and is currently mounted on a one meter mast. The Airmar PB-200 detects instantaneous changes in weather and measures wind speed and direction through its ultrasonic transducers. The sensor also measures air temperature and humidity. The sensor has no moving parts, which enables it to have better durability and reliability. Through its internal WAAS GPS engine and three-axis, solid-state compass the Airmar PB-200 is capable of providing both apparent and true wind direction. This sensor has been tested to 2 degrees accuracy under dynamic conditions including rough seas and has provided highly accurate and stable measurements, even in sea conditions that caused a vessel to pitch and roll at 30 degrees. Energy requirements are minimal and will require less than 3 Watt-hours.

RESULTS

The initial goal of this project was to integrate an OA sensor package within a Wave Glider drybox that could be deployed and tested at the end of the ten-week internship period. While it was possible to integrate the necessary electronics into the aft drybox by the end of the internship period, a completely integrated Wave Glider ready for deployment did not occur. The initial goal was quite ambitious, although this project did initiate a project that can feasibly be completed within the next two months.

As of Friday, August 12, Liquid Robotics and MBARI have established a set of goals that are required for the full integration of Wave Glider OA system. Engineers at Liquid Robotics are currently working on a hull design to accommodate a CTD, pH, and Oxygen sensor with the CO_2 equilibrator. Liquid Robotics has agreed to design a hull fairing that will house a CTD, pH and oxygen sensor and an MBARI designed equilibrator. Gernot Friederich, a research specialist at MBARI will be designing a new equilibrator in the up coming weeks, which will then be sent to Liquid Robotics for integration into a Wave Glider hull.

Communications between the Wave Glider drybox and the MBARI OASIS control board has yet to be established, however Bob Herlein, a software engineer at MBARI, is currently working closely with Liquid Robotics software engineers to establish communication between both systems. Once communications have been created and hardware has been designed the Wave Glider OA sensor suite can be installed into the float and testing can occur. Currently Liquid Robotics is very enthusiastic about this integration project and is considerin providing a test Wave Glider for the testing of MBARI's OA sensor suite in upcoming deployments along the north east coast.

CONCLUSIONS

During the MBARI's 2011 summer internship program MBARI's OA mooring sensor package was successfully integrated into a Wave Glider drybox. This project helped spark interest from Liquid Robotics Inc., who is very willing to assist in the integration process as much as possible. Over the past ten weeks I worked through the integration process piece by piece by communicating with scientists and engineers at MBARI and Liquid Robotics to ensure the completion of this project. During this process I had to learn an entire new set of skills that were very technical and different from my environmental management and policy background. Learning these skills exposed me to the complex processes involved in implementing a successful engineering project and provided me with a better understanding of what capabilities certain technologies have and how they can be implemented into ocean observing systems for better management of the marine environment.

Gaining such valuable experience is extremely important for the management and conservation of the marine ecosystem because there is often a lack of communication between scientists and engineers and those people making important management decisions. Developing a link between these groups and understanding how each side works is essential for successful environmental management. This internship proved extremely successful in linking two diverse components of marine management, specifically by providing insight into the necessary steps required for scientists, engineers, and managers to make monitoring technologies available for ocean observation systems.

Finally, more platforms like the Wave Glider ASV are required if researchers are to develop a better understanding of how increased levels of CO_2 are affecting the marine ecosystem. Autonomous vessels are an effective means of performing ocean acidification research because they provide a cost effective means of collecting data over large temporal scales. ASV technologies are also capable of increasing the spatial scales at which oceanographic features can be measured, which enables researchers to continuously monitor large areas for extended periods of time. Currently ocean observing systems like CeNCOOS (Central and Northern California Ocean Observing Systems) are attempting to increase the types of monitor methods that are used to observe the California coast. CeNCOOS is seeking the most effective and cost efficient methods in order to meet these needs. In theory 3-4 Wave Gliders equipped with MBARI's OA sensor package could satisfy CeNCOOS's observation needs by providing persistent observations and data collection to the CeNCOOS region that could be utilized by a variety of different stakeholders. While the Wave Glider is not the only potential method for effective observation and data collection of marine environments, it is a very good option that should certainly be tested.

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