Artemis AUV Payload Development

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Abstract—Phoenix engineers and operators have been working on developing new payload capabilities for our Autonomous Underwater Vehicle (AUV) Artemis. Initially, we integrated and demonstrated a payload designed to look for hydro-carbon leaks from subsea pipelines. More recently, we developed a magnetometer payload for locating and mapping seafloor minerals. Both of these efforts involve the use of an AUV payload computer and a set of open source C++ modules for providing autonomy on robotic platforms, in particular autonomous marine vehicles, called Mission Oriented Operating Suite - Interval Programming (MOOS-IvP). This paper will discuss these AUV payload development efforts and describe how Artemis is now ready to support additional payload development initiatives.

Keywords— Phoenix International Holdings, Inc., AUV, Artemis, Payload, Autonomy

I. Introduction

Artemis, the Phoenix-owned Bluefin-21 Autonomous Underwater Vehicle (AUV), is preparing for a seafloor geophysical mineral survey scheduled for September – October 2015 in the South Pacific. The significant part of this development is the creation of a payload computer capable of integrating and recording data from a variety of payload sensors and simultaneously geo-referencing the data by integrating time-stamped data from the AUV's main computer. In other words, Phoenix has developed the capability to add payload based sensors to Artemis and use it as a platform to deliver those sensors in support of subsea mission objectives. Using our newly developed payload integration computer, our AUV is now capable of employing a variety of sensors and connecting all collected sensor data to subsea positioning data – all while utilizing the many normal benefits of an AUV, such as: a terrain following capability at a set altitude, the ability to follow a pre-programmed course, the ability to turn in 1.5 times its body length (30 feet), and the ability to travel between 2-5 knots. Figure 1 shows Artemis during MH370 search operations in the Southern Indian Ocean. In addition, all of these capabilities come packaged in a highly portable system with modular payloads designed to operate from various vessels of opportunity.

Figure 1: Artemis During MH370 Search Operations

II. MOOS-IvP Compliant Payloads

While the vehicle's initial two payloads were considerable: 1) a side-scan sonar, multi-beam echo sounder, and sub-bottom profiler and 2) a high-resolution camera; for some customers these capabilities were not adequate. Seeing the need to develop additional payloads to expand the vehicle's capabilities, Phoenix collaborated with the Massachusetts Institute of Technology (MIT) Laboratory for Autonomous Marine Sensing Systems (LAMSS). This collaboration led to our adoption of Mission Oriented Operating Suite MOOS-IvP, a set of open source C++ modules for providing autonomy on robotic platforms, in particular autonomous marine vehicles.

MOOS-IvP is an Open Source Autonomy project comprised of the MOOS publish-and-subscribe middleware and the IvP Helm Autonomy behavior based architecture. It was initially developed by Paul Newman in 2001 to support operations with autonomous marine vehicles in the MIT Ocean Engineering and Sea Grant programs. MOOS and the IvP Helm provide two architectures that enable the autonomy and sensing system to be built from distinct and independent modules. The software runs from a payload computer that receives vehicle position and heading information from the main vehicle computer. It provides a backseat driver capability in that the payload computer can provide vehicle heading, depth, and speed commands back to the main vehicle computer. The payload computer provides these commands based on decisions made by the autonomy software from the input data received from the payload sensors. This MOOS-IvP

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backseat driver capability gave Phoenix engineers the capability to develop sensor payloads for Artemis.

III. Initial AUV Payload Development

Our first AUV payload development and integration effort was in support of an offshore oil application that required the integration of leak detection sensors into Artermis. The goal of the project was to demonstrate the AUV's ability to locate pipeline gas leaks, fly through the leak without human intervention, and then analyze the volume and content of the leak. In order to do this, both software and hardware modifications to the vehicle were required. The software modifications included the installation of a software interface that allows the main vehicle computer to accept guidance commands from the payload computer. With these modifications in place – as well as leak detection sensor technology – the AUV was used to conduct a two week demonstration in Massachusetts Bay in early 2015. During these trials, the AUV successfully demonstrated its new ability to perform leak detection operations.

With a new payload, consisting of a mass spectrometer, forward and downward looking high frequency sonars, coupled with a payload computer running MOOS, the AUV was now configured to look for subsea hydrocarbons. During the demonstration, the vehicle was programmed to steer a specified course at a specified altitude above the bottom until it detected indications of hydrocarbons. The payload computer, based on the data collected by the sensors, would then autonomously give the vehicle both a horizontal and vertical offset to the target. The vehicle would then fly through the target and return to its original behavior. At the conclusion of the demonstration, the leak detection technology was removed, but the capability to operate with a backseat driver remained.

IV. Subsea Mining Payload Development

Our latest AUV payload design was developed to address a subsea mining application. The goal for this payload was to use the AUV to perform mapping and detection of Seafloor Massive Sulfide deposits in water depths down to 3000 msw. We integrated a magnetometer capable of detecting magnetic fields in the nanotesla (nT) range, a self potential sensor capable of detecting electric fields in nanovolt/meter (nV/m) range, and a conductivity-temperature-depth (CTD) sensor. In addition to those three sensors, the project requires the AUV to simultaneously collect bathymetry and backscatter data with its existing Reson 7125 Multibeam Echo Sounder. Lastly, the project requirements mandated linking all sensor data to the vehicle's navigation data – along with a time stamp – at a data logging rate of 10 Hz.

When any metallic body is immersed in seawater it becomes polarized due to dissimilarities in the alloys or metals due to imperfections in the grain structure, the result is a dipole with an associated electric field. These dipole fields are generated by ferrous and non-ferrous metals alike. The self potential sensor, using a pair of silver-silver chloride (Ag/AgCl) cells, can detect these electric fields, measuring voltage gradients at levels as low as a few nV/m. The cells have very low drift and also are very low noise, <0.3 nanovolts per root hertz (nV/√Hz).

The Ag/AgCl cells were connected to high gain differential amplifiers. These very low noise amplifiers, typically 1 nV/√Hz, have a flat frequency response of 0.005 Hz to 14 kHz with a maximum gain of 86 dB (i.e., a maximum voltage gain of 20000). The vehicle has three amplifiers installed, one for each axis, and can record data for all three axes to a dedicated hard disk. Presently, the vehicle sensors are configured to collect data only in the y-axis. The amplifier output was digitized using a 24-bit sigma-delta (ΣΔ) analog-to-digital converter with a Serial Peripheral Interface bus interface to the payload computer, where the readings were scaled and logged as a voltage gradient in nV/m.

We selected the Honeywell HMR2300 Fluxgate Magnetometer, a three axis smart digital magnetometer, to detect the strength and direction of an incident magnetic field. It has a range of ±0.2 millitesla (mT) and a resolution of <7.0 nT with an accuracy over ±0.1 mT of <0.5% of full scale. The sample rate can be set from 10 to 154 samples per second.

To minimize the negative effects of self generated electric and magnetic fields associated with the vehicle, several steps were taken. The magnetometer was mounted in a separate pressure housing in the nose of the AUV, thus keeping it as far away as possible from any vehicle generated magnetic fields. The electric field sensors were spaced apart as much as possible by mounting them longitudinally inside the hull of the AUV with a spacing of 3.0 meters. To reduce the effects of the fields generated by the main propulsion motor, the aft sensor was mounted 1.5 meters forward of the tail cone. To minimize noise associated with the self potential sensor amplifiers, all cables were screened and the amplifiers were housed in shielded boxes.

The first bench test was performed using a payload prototype board and proved successful at logging the sensor data in the client's specified data format. Next, the actual payload hardware was completed and the full payload with all sensors installed was integrated into Artemis and the vehicle was successfully tested in the dry. The AUV was then placed in our test tank for two separate eight hour dives, during which the vehicle successfully logged data from all of the payload sensors. Figure 2 shows the fully assembled payload prior to at sea testing.

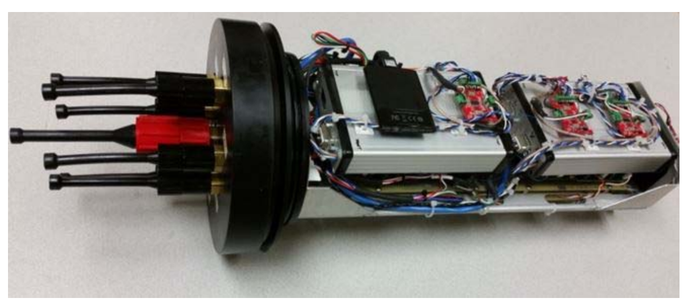

Figure 2: Fully Assembled Magnetometer Payload

Following these payload development efforts, Artemis was mobilized to the Gulf of Mexico to undergo a series of dockside and offshore trials. While offshore, calibration of the magnetometer was completed by switching on all of the sensors and positioning Artemis at least 500 meters away from the support vessel. The AUV then submerged to a depth of 500 meters where it swam in figure-eight patterns while recording vehicle-generated magnetic field levels to obtain a baseline. The next task was to place a test fixture on the seabed. The test fixture consisted of a steel pipe 15.0 centimeters diameter and 5.0 meters long with two 1.32 Tesla neodymium magnets mounted to the pipe with 1.0 meter spacing. The test fixture also included a zinc block on one end and a copper block on the other. With this test fixture, the AUV now had a good target to test the magnetometer and electric field sensors associated with the vehicle's new magnetometer capability. During the trials, conducted in August 2015 off Port Fourchon, LA, Artemis successfully located the test fixture and, following vehicle recovery, the collected data was processed and verified as accurate. Our subsea mining payload will see its first operational mission in the Fall of 2015.

V. Future Payload Developments

Our series of successful payload developments have significantly enhanced our AUV's capabilities by furnishing it with a payload computer designed to time stamp and geo-reference sensor data from a wide range of sensors. This payload computer, using MOOS-IvP software, can then make autonomy decisions based on the input from these sensors and then provide the vehicle main computer with guidance commands. We have already discussed future payload requirements with our customers and have begun development, all of which will require more complex autonomous behaviors from Artemis. All of these capabilities will be driven by the backseat driver capability of the payload computer.

Acknowledgment

The authors thank Dr. Henrik Schmidt and Dr. Michael Benjamin of MIT LAMSS and Dr. Stephanie M. Petillo and Dr. Toby E. Schneider of Gobysoft, LLC for their technical assistance with payload development for Artemis.

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