Ocean Deployment and Testing of a Semi-Autonomous Underwater Vehicle

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***Abstract*—We present the design overview and results for an offshore deployment of a semi-autonomous underwater vehicle (sAUV). The system is based on a commercially-available observation class remotely-operated vehicle (ROV), combined with a commercial AUV navigation system. The vehicle also has onboard visual cameras, a Doppler velocity log, and a multibeam imaging sonar. We present the integration of the various subsystems as well as a Robot Operating System (ROS)-based interface that allows researchers to visualize sensor and navigation data and send commands to the vehicle in real time. Results from an April 2016 offshore trial are presented, demonstrating the station keeping and waypoint-following capabilities of the vehicle in open water.**

I. Introduction

While remotely-operated vehicles (ROVs) are a relatively mature technology, they can be costly to operate due to the requirement for constant human control. Human operation of ROVs is particularly challenging because it requires a high degree of operator training and skill, and the constant attention can be draining to a human operator. In order to reduce operator load, ROVs are a strong candidate for introducing autonomy to reduce operator load in simpler tasks, such as station-keeping and traveling between known positions. While these tasks are routine for autonomous surface and aerial vehicles, the challenges of underwater navigation and communication have reduced the number of deployed autonomous underwater vehicles [1], [2]. Consequently, deployment of Autonomous Underwater Vehicles (AUVs) remains generally limited to research institutes and governmental departments for scientific data collection. However, recent developments in sensor and underwater vehicle technology have reduced the cost barriers to developing autonomous underwater vehicles. To this end, we demonstrate the operation of a low-cost platform developed primarily from commercially-available components with a total value of approximately US$150k. This is significantly less than existing solutions that cost over US$500k [3]. We also present a software interface based on the popular open-source Robot Operating System (ROS) that allows a user to visualize the robot in real-time, access data streams and send basic commands to the robot.

II. System overview

The system is based on the Seabotix vLBV300 observation-class [4] ROV platform. The vLBV300 is a small tethered vehicle with a dry mass of approximately 19.0 kg given minimal sensor load. In the current configuration with a full sensor load, the vehicle has a dry mass of 36.2 kg, including 2.0 kg of ballast for operation in seawater. The vehicle is rated to a depth of 250 m and has a 350 m tether. This tether provides both power and communications with the vehicle through an ethernet and serial interface. The vLBV300 platform is a vectored thrust vehicle with six thrusters. Two vertically-aligned thrusters provide vertical lift, and four angled lateral thrusters provide horizontal in-plane motion and rotation. The vehicle is passively stable in roll and pitch, and thus in normal use has four controllable degrees of freedom (roll is possible by providing differential thrust to the vertical thrusters but is not commonly used).

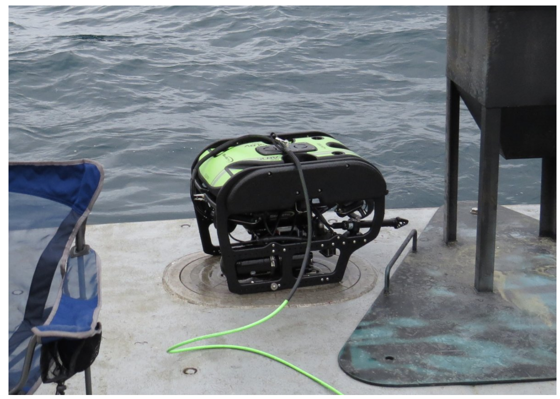
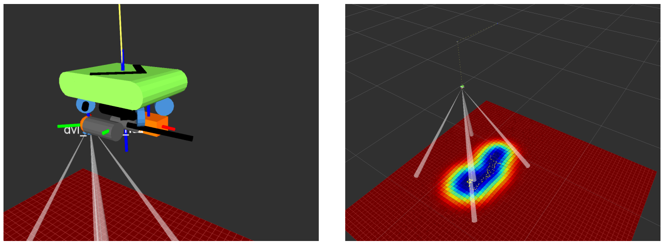


Fig. 1. sAUV on deployment near Newport, OR.

Navigation is provided by a Greensea INSpect GS3 navigation system. The navigation system is primarily based on a microelectromechanical system accelerometer and gyroscope, providing three-axis acceleration and rotation rate data, and a three-axis magnetometer. The navigation system also fuses data from the onboard Teledyne Explorer Doppler velocity log (DVL) that provides lateral velocity estimates and range information. The DVL uses a four-beam phased array antenna with frequency 614.4 kHz. Finally, the vehicle has a Tritech Gemini multibeam imaging sonar that provides sonar data for underwater navigation.

III. ROS interface

To provide easier access to sensor data and vehicle control we developed a ROS interface for the sAUV system. ROS is



(a) Navigation visualization. (b) Depth GP model.

Fig. 2. ROS rviz visualization. The ROS based interface displays live navigation data to visualize the robot pose (2a) and prcoess sensor data. A simple bathymetry estimator is shown in 2b that uses GP regression from DVL depth estimates (grey cones), where the colors of the base map indicate uncertainty.

an open-source middleware platform for controlling and developing applications for robotic systems [5]. ROS is popular in the robotics research community due to the high number of freely-available applications [6].

By bringing data from the navigation system, sensors and manual commands into the ROS system, it becomes relatively straightforward to generate visualizations and process sensor data. Figure 2 shows some sample images from the ocean deployment described below. A simple 3D model can be used to show the estimated vehicle position and orientation in real time. Subfigure 2b illustrates a simple application, using a Gaussian Process regression model [7] to construct an estimated bathymetry map from DVL range data. These types of data are useful for planning missions, either fully autonomously or human-aided.

IV. Ocean deployment

The system was deployed for a test mission near 44.678° N 124.109° W, approximately 2 km offshore of Yaquina Head near Newport, Oregon on 20 April 2016. The primary goals of the deployment were to demonstrate station-keeping and waypoint following capabilities in ocean conditions and to demonstrate the ROS-based interface.

The deployment was conducted from the R/V Elakha, a 54 ft Class III research vessel owned and operated by Oregon State University. The deployment consisted of three dives to conduct tests at depths ranging from the surface to approximately 45 m. Total dive time was approximately 80 minutes. During the mission period, the sea state varied between 3 and 4 [8], with an average significant wave height of 1.6 m.

V. Navigation performance

One of the primary goals of the offshore deployment was to analyze the navigation performance of the vehicle. In particular, we were interested in how well the vehicle would perform at different depths, under the varying effect of wave forces (which tend to decrease with depth) and current forces. During the offshore trial we collected data while the sAUV was uncontrolled, attempted to station-keep at a single position, and performed lateral square patterns at a variety of depths to characterize the sea state and controlled performance

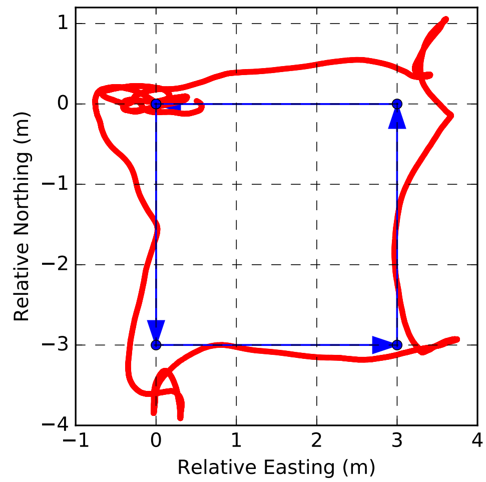


Fig. 3. Vehicle moving around a commanded 3 m square pattern at 10 m depth. Arrows indicate the commanded position sequence, starting from (0,0). Total time was approximately 120 seconds, with a short (10 s) pause at each waypoint.

of the vehicle. Figure 3 illustrates the internal position estimate of the vehicle during execution of a 3 m square pattern at 10 m depth. Uncontrolled at the same depth, the vehicle drifted approximately 0.13 m/s easterly due to the current and experienced wave forces that resulted in lateral and vertical motions of around 0.5 m. The results show that the controller can reach and traverse between waypoints to within approximately 1 m with respect to the internal navigation solution. This suggests that the vehicle has sufficient actuation authority to maintain position in open-ocean conditions. Ongoing research will use a frequency analysis approach to tune controller gains to meet tighter performance specifications.

Obtaining an external ‘ground truth’ navigation estimate is especially challenging for underwater vehicles [1]. To attempt to characterize the navigation performance we performed a set of maneuvres near the sea floor (altitude < 5 m) with visible sonar features to allow an external estimate of the navigation performance. Analysis of this data is ongoing and will be presented in the full paper.

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