A New Hydrodynamics Test Facility for UUV Dynamics and Control Research

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Abstract

This paper reports the development of a new hydrodynamics test facility for UUV dynamics, navigation, and control research. Located at the Johns Hopkins University, the facility's 174,000 liter water tank, navigation instrumentation, and testbed ROV provides the ability for development of advanced underwater vehicle systems. Experimental data demonstrating the performance of the facility's sensor suite is presented. This paper briefly discusses the facility's recent role in the development of control and navigation systems for operational oceanographic underwater vehicles.

1 Introduction

This paper reports the development of the Johns Hopkins University's Hydrodynamics Test Facility and describes its use in UUV research. The facility is equipped with a water tank and the *JHUROV* laboratory research ROV. The vehicle is instrumented with a variety of navigation sensors, including a Doppler sonar, a three-axis fiber-optic gyroscope, and an Imagenix sonar. The tank is equipped with a 300kHz LBL system that provides sub-centimeter XY position measurement and heading measurement to within a tenth of a degree. The control system developed for the *JHUROV* has been adopted for use on several new oceanographic vehicles. This facility enables us to conduct vehicle experiments in a controlled environment prior to sea deployment, thus accelerating UUV research.

Previously reported experimental underwater vehicles and vehicle test facilities have been reported by researchers at WHOI [11], the Naval Postgraduate School [6], the University of Hawaii [3], Stanford University and MBARI [8], the University of Maimi [12], the University of Sydney [18], Institute for Ship Automation of the National Research Council in Italy [2], IFREMER [13], and the University of Tokyo [4]. To the best of our knowledge, the navigation instrumentation at the new Johns Hopkins Hydrodynamics Test Facility combines, in a single system, all of the types of vehicle navigation sensors reported in these previous studies.

2 The Hydrodynamics Test Facility

This section describes the Johns Hopkins University Hydrodynamics Test Facility. The facility is designed for the development and testing of oceanographic systems. A test tank, laboratory ROV, and suite of navigation instruments provides the ability for the development of underwater vehicle systems. This section discusses the facility and its role in UUV research.

2.1 Test Tank

The Hydrodynamics Testing Facility (Figure 1) is equipped with an indoor fresh water tank measuring 7.49 meters in diameter and 3.96 meter deep, with a capacity of 174,000 liters. Three 0.6 meter square windows allow for observation

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and enable optical experiments. Two 1-ton overhead gantry cranes provide lifting ability over the entire tank, adjacent staging area, and workshop. The 11.5 meter by 3.0 meter workshop is equipped for the development, testing, and repair of oceanographic systems. AC power ranging from 120V to 480V can accommodate a wide variety of experiments.

2.2 *JHUROV*

The *JHUROV* is a platform for experimental research in UUV dynamics, navigation, and control. Built by Johns Hopkins students, the *JHUROV* is a 140kg, 1.5m x 1m x 1m ROV with a 1000m depth rating. The vehicle is passively stable in roll and pitch. Six thrusters are reconfigurable to allow for 6-DOF vehicle dynamic experiments.

Each on-board sensor is connected to one of the vehicle's six communication ports. Each connection provides 24VDC power and utilizes RS-232 serial data telemetry, allowing for a wide variety of sensors to be connected with minimal setup. A Digi International TS8 terminal server provides transparent multiplexing of the RS-232 signals from the vehicle via the ethernet through the vehicle tether to the surface computer system. Each of the eight TS8 serial ports can be remotely accessed on any surface computer, thus enabling users to communicate with any sensor while the vehicle is in operation. Surface computers are synchronized to a common NTP time server and utilize UDP network connections to provide distribution and logging of on-board data. The telemetry and computer systems, along with the ability to rapidly change the configuration of the vehicle, give the *JHUROV* flexibility to accommodate a wide variety of experiments, e.g. [14, 15].

The *JHUROV* is actuated by instrumented thrusters that enable us to study thruster dynamics. Designed and built by Johns Hopkins students, these 1.5 kW 3 phase DC permanent magnet brushless thrusters each provide 150 N peak thrust. A Copley 513R Current Mode Amplifier precisely controls each thruster, and a resolver measures the angular shaft position with a resolution of 4096 counts/revolution [14]. Precise measurements of the input power, shaft angular position, and shaft angular velocity enable thruster dynamics experiments.

The vehicle uses LBL acoustic navigation [7, 10] and Doppler navigation [1, 17] techniques for estimating the vehicle's XY Position. The sensors and systems used for navigation are described in Section 2.3.

The *JHUROV* control architecture consists of two main modules: the surface computer system and the sub-sea system. The surface control system consists of several desktop computers connected by Ethernet or serial lines. A Linux PC serves as the vehicle control computer, and a Windows 2000 PC provides a GUI interface. Thruster management is run in a sub-sea PC/104 computer [14, 15]. The *JHUROV* control system has been adopted for use by several new oceanographic ROVs, including WHOI's *DSL-120A* and *Jason II*[1], the Southampton Oceanography Center's *ISIS*[2], and the Institute for Exploration's *Hercules*[3][16].

Readers are referred to the *JHUROV* homepage[4] for more information.

2.3 Navigation Instrumentation

The Hydrodynamics Test Facility is equipped with a suite of navigation sensors. Many of the sensors are similar in nature to those found in oceanographic UUVs, enabling navigation and control systems developed at the facility to be readily transferred to at-sea vehicles. Table 1 lists the sensors currently employed at the facility.

The 300kHz LBL acoustic navigation system

[1]National Deep Submergence Facility, Woods Hole Oceanographic Institution, www.whoi.edu/marops/vehicles

[2]United Kingdom Deep Submergence Remotely Operated Vehicle Facility, Southampton Oceanography Center, University of Southampton, www.soc.soton.ac.uk/OED/ROV

[3]Institute for Exploration, Sea Research Foundation, www.ife.org

[4]robotics.me.jhu.edu/dscl/jhurov

Figure 1: The Hydrodynamic Test Facility at the Johns Hopkins University. The tank is 7.75 meters in diameter and 4.25 meters deep. The *JHUROV* is visable on the platform and the adjacent workshop is in the background on the right.

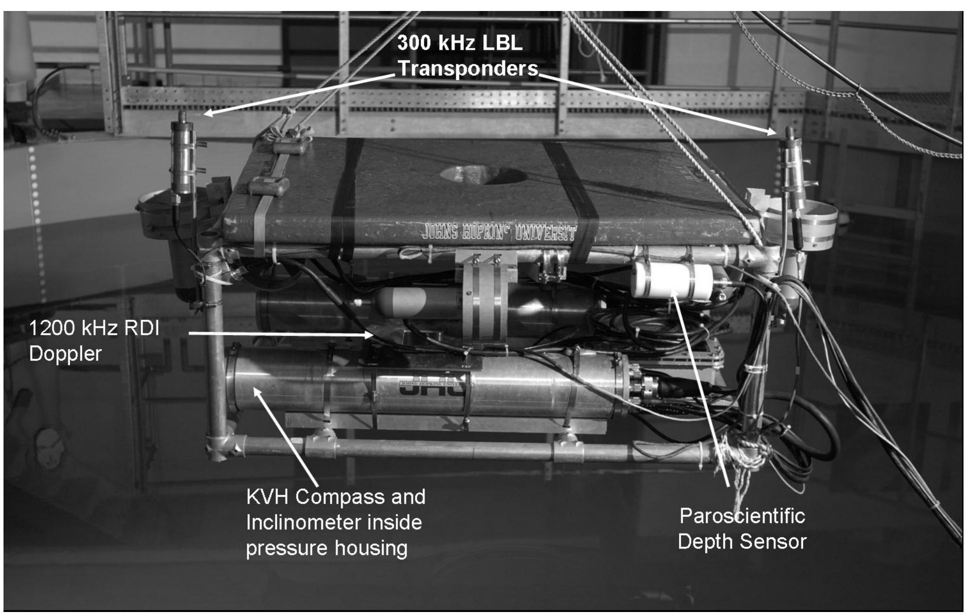
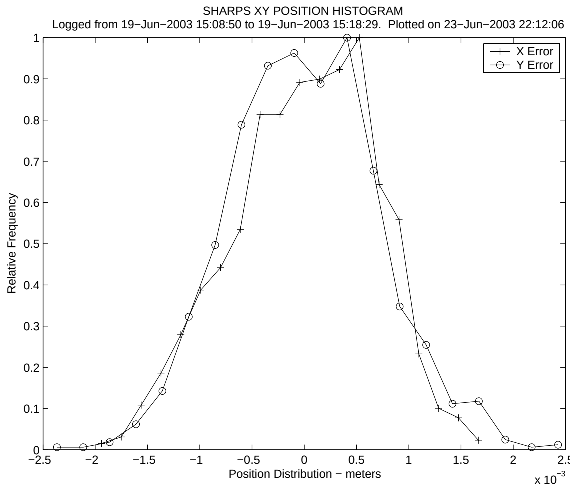


Figure 2: The location of various sensors on the *JHUROV*. The vehicle's extensive instrumentation enables UUV research.



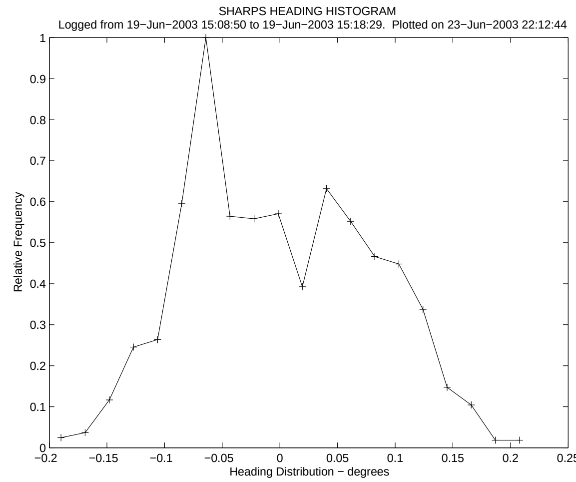


Figure 3: Results of a recent experiment testing the repeatability of the 300kHz LBL navigation system. The histogram on the left shows the relative frequency of the vehicle's X and Y position with respect to their mean values. Standard deviations are 6.7517×10^{-4} meters and 7.0354×10^{-4} meters for X and Y respectively. The right plot shows the relative frequency of the heading estimate. The heading estimates has a standard deviation of 0.0792°.

provides precision time of flight ranges from each of the four transponders. Two transponder are mounted on the tank and two are mounted on the ROV. When coupled with the Paroscientfic depth sensor[5], the system can compute the XY position of the vehicle. Multiple vehicle mounted transponders enable the LBL system to measure heading.

Figure 3 shows data from an experiment to evaluate the repeatability of the 300 kHz LBL system. The *JHUROV* was held immobile for 10 minutes, while the 300kHz LBL system computed the vehicle's position. The standard deviations of the vehicle's X and Y positions during the experiment were 6.752×10^{-4} meters and 7.035×10^{-4} meters, respectively. The standard deviation of the heading measurement was 0.0792°. The left plot of Figure 3 shows the histograms of the *JHUROV's* X and Y positions and the right plot shows the histogram for heading.

A KVH ADGC gyro-stabilized compass[6] and a flux-gate compass mounted in the Doppler sonar provide heading estimates with approximately 1° precision. A Crossbow three axis fiber-optic gyroscope[7] also measures heading. While the gyro is not North-seeking, it can be initialized to North using the heading measurement from the 300kHz LBL. This ability to measure heading with different types of sensors and compare them with the LBL's accurate and precise heading estimate enables research into the effects that heading estimates have on vehicle navigation[9].

Vehicle velocity is instrumented with a 1200kHz RDI doppler sonar[8]. Velocity estimates are provided by the Doppler up to 10Hz and are accurate to within 1%. The Doppler position is computed in DVLNAV[9], an integrated navigation system for manned and unmanned submersibles developed by the authors. The DVLNAV navigation system is employed on WHOI's inhabited submersible *DSV Alvin* and on the remotely operated vehicles *DSL-120A*, *Jason II*, *ISIS*, and *Hercules*[9]. Figure 4 shows an example of the *JHUROV's* XY position as computed by the LBL system and DVLNAV. The high update rate and precision of both the LBL and Doppler navigation systems enables the

[5] Paroscientific, www.paroscientific.com
[6] KVH Inc, www.kvh.com
[7] Crossbow Inc, www.xbow.com
[8] RD Instruments Inc, www.dvlnav.com
[9] Dynamical Systems and Controls Lab, DVLNAV homepage: robotics.me.jhu.edu/dscl/dvlnav

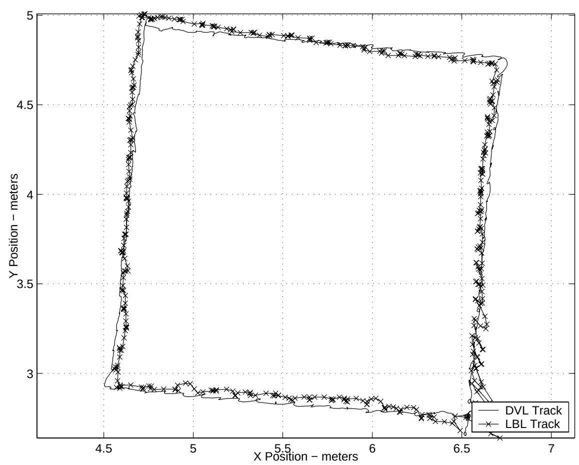


Figure 4: An example the *JHUROV's* XY position in the world frame as computed by the LBL time of flight acoustic navigation system and the DVLNAV Doppler navigation system.

JHUROV to use either system for closed loop control.

A Deep Sea Power and Light camera[10] is mounted on the ROV and can be employed to estimate the vehicle's position via computer vision techniques. The data is processed by XVision[11], a software package for visual tracking and motion estimation[5]. This system allows for research into the potential uses of visual navigation in UUVs.

3 Conclusion

This paper reported the development of a new test facility for UUV research. The facility is equipped with a 174,000 liter water tank and a well instrumented ROV. Many of the sensors provide high precision measurements, enabling UUV research in a variety of areas including navigation and control. UUV navigation [9] and control systems [16] developed by the authors and collaborators have been adopted for use on several oceanographic ROVs and the human occupied vehicle *DSV Alvin*.

[10] DeepSea Power and Light; www.deepsea.com

[11] Computational Interaction and Robotics Laboratory, Department of Computer Science, The Johns Hopkins University. www.cs.jhu.edu/CIRL

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Table 1: Sensors Currently Employed at the Hydrodynamics Testing Facility

VARIABLE	SENSOR	UPDATE RATE	PRECISION
Heading	KVH ADGC	10 Hz	1°
Roll and Pitch	KVH ADGC	10 Hz	0.1°
Attitude	Crossbow IMU700CA	125Hz	0.025°
Heading	300kHz LBL	5Hz	0.1°
XYZ Position	300kHz LBL	5Hz	0.5 cm
XYZ Velocity	RDI 1200kHz Doppler Sonar	10Hz	0.3%
Depth	Paroscientific	Analog	0.75%
Color Video Image	DSPL 2050 Multi-Seacam	30 Frames/sec	NTSC Standard
Propeller Position	Resolver	1000 Hz Max	4096 counts/revolution
Range and Bearing	675kHz Imagenix Profiling Sonar	20Hz	10mm

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