A New Autonomous Underwater Vehicle for Imaging Research

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Abstract— **Currently, unmanned underwater vehicles either tend to be cumbersome and complex to run, or operationally simple, but not quite suitable platforms for deep water imaging. Aware of the currently existing capabilities of unmanned underwater vehicles, this paper presents an alternative design in the form of a new low cost and easier to use autonomous underwater vehicle (AUV) for imaging research. The objective of the vehicle is to serve as a readily available and operationally simple tool that allows rapid testing of imaging algorithms in areas such as: photomosaicking, 3D image reconstruction from a single camera, image based navigation, and multi-sensor fusion of bathymetry and optical data. These are all current topics of research within the Deep Submergence Lab at the Woods Hole Oceanographic Institution, but that lack a devoted and specific platform to their study. Regarding the new vehicle's operational simplicity, it is intended to be small boat deployable with an operation time of ten hours. The vehicle will also have the capability for scientific work in waters of up to 2000 meters in depth. This depth restriction represents a breakpoint in vehicle cost and design complexity while still providing a large area of survey interest. Initially, the vehicle will be primarily devoted to optical imaging close to the ocean floor, but it's design will allow for future sensor integration. Therefore, key design parameters in the new vehicle are: hovering capability, passive stability, and object avoidance. An overview of the vehicle's first iteration design philosophy and key subsytems along with a preliminary dynamic model and results of hydrodynamic testing are described herein.**

I. INTRODUCTION

State of the art exploration of underwater sites requires a vehicle with functionality for many different tasks. This paper outlines the preliminary design of a new autonomous vehicle for underwater surveying. This vehicle will be used to collect data and test algorithms for topics of research like underwater photomosaicking, 3D image reconstruction, microbathymetric mapping, image based navigation and underwater vehicle dynamics and control. The design requirements for the vehicle are outlined and descriptions of the major vehicle subsystems are given. Initial results for thruster and drag tests are also given and discussed.

II. SHAPE AND MANUVERABLITY CONSIDERATIONS

The ability to survey and image an area requires that the vehicle has at least four degrees of freedom. The vehicle should be able to translate and rotate in a plane as well as control its depth. For simplicity, we would like a design which is passively stable in the remaining two degrees of freedom, pitch and roll. The vehicle should be able to hover in a particular location and not require fluid flow over control surfaces. These constraints are also coupled with the desire to create a vehicle with low hydrodynamic drag in its primary direction of motion. To meet these needs we propose the two body shape shown in figure 1. The two body shape allows for a large separation between the center of gravity and center of buoyancy, as well as passively stabilizing the pitch and roll motions of the vehicle. The top section of the vehicle contains flotation, electronics housing with processing stack, attitude sensors, thruster controllers, LBL navigation, depth sensor and beacons. The bottom section has the battery housing, doppler, optical and acoustical surveying sensors and the ascent/descent mechanism. The thruster locations were chosen to achieve the necessary four degrees of freedom using four thrusters. The symmetric shape should minimize the effects of the hydrodynamic cross coupling terms. The overall length of the vehicle is approximately 1.5 meters. Each hull is .3 meters in diameter and the overall vehicle weight is on the order of 110 Kg.

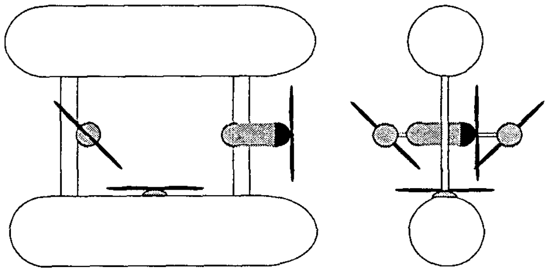

Fig. 1. Side view and front view of the vehicle

Preliminary towtank experiments using the model shown in figure 2 have been completed to estimate the drag and stability of the proposed shape. A load cell assembly was fabricated to push the vehicle through the towtank and measure the retarding drag force. The towtank test was used to compare the drag of the scale model and compare it to the drag predicted using Hoerner's fluid dynamic drag [1]. Using drag coefficients for similar hull shapes and faired struts, based on frontal area, the estimated total drag coefficient is between .35 and .4. The experimental test produces a drag coefficient of .5. The drag tests were also used to compare the relative effects of thruster placement and body fairing. Towing the model through the tank with a string indicated that the shape is heading unstable,

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as would be expected with a slender body shape. The aerodynamic center is located approximately one third of a body length ahead of the vehicle.

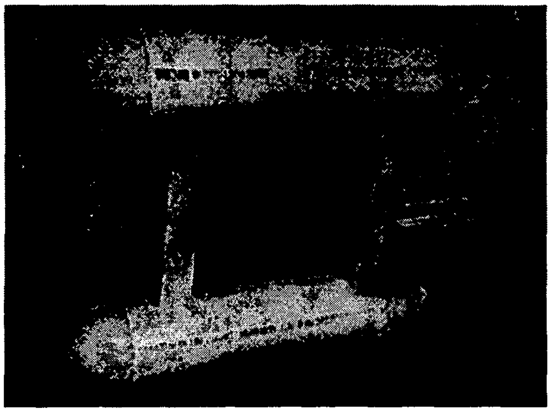

Fig. 2. $\frac{1}{3}$ scale test model of the vehicle shown with pushing stinger

III. INITIAL SENSOR SUITE

The initial sensor suite is chosen to compliment research interests combining acoustic and inertial navigation with photo imaging and high resolution sonar sampling [4] [5] [8] [9] [10]. Having a single vehicle which can gather data in several modalities is extremely valuable, as testament by the success of the JASON ROV with forensic and geological operations as well as deep water archeology and exploration [2] [3] [6] [7].

A. Navigation and dynamics

Accurately surveying an area requires reliable navigation information. The navigation sensors will include

- Acoustic Doppler Current Profiler (ADCP) to be used in bottom lock operation and measure ground relative velocities. The velocity measurements are accurate to .4 % actual velocity.
- Long Base Line (LBL) receiver for long range position information accurate to the order of 1-10 meters.
- TCM2 pitch, roll and heading sensor which will measure pitch and roll to .2 degrees and heading to 1 degree.
- GYROCHIP angular rate sensor to measure yaw rate, accurate to .05 degrees/sec. The GYROCHIP's analog output will be interfaced to the main computer through a signal processing board which filters the sampled yaw rate signal.
- Paroscientific depth sensor used for depth surface relative depth measurement to .01% accuracy.

Experiments with similar navigation suites on the ROV Jason lead us to expect positioning errors on the order of 0.1 to 0.2 m when using LBL in combination with doppler data. Update rates of 4-5 Hz are possible, enabling actual position-based closed loop control.

B. Data collection

- MULTI-SEACAM 2050 black and white CCD camera will be used for recording all digital images.
- Vivitar Strobe for camera lighting
- Imagenix pencil beam sonar for collecting bathymetric information

IV. THRUSTERS

The vehicle thrusters are brush type DC motors enclosed in one atmosphere pressure housings. Oil compensated thrusters were not used due to the losses inherent of running motors in oil. The thrusters are controlled using a pulse width modulation controller with current feedback.

Preliminary experiments have been performed to validate the steady state performance of the thrusters using several different propellers. Bollard pull tests have been performed to estimate the maximum thrust which can be generated using a propeller 22 inches in diameter with 10 inches of pitch. The results of this test, shown in figure 3, for a steady state operation show a nearly linear relation between motor current and thrust. These tests were performed in tow tank with the thruster mounted to a mechanical arm and load cell assembly.

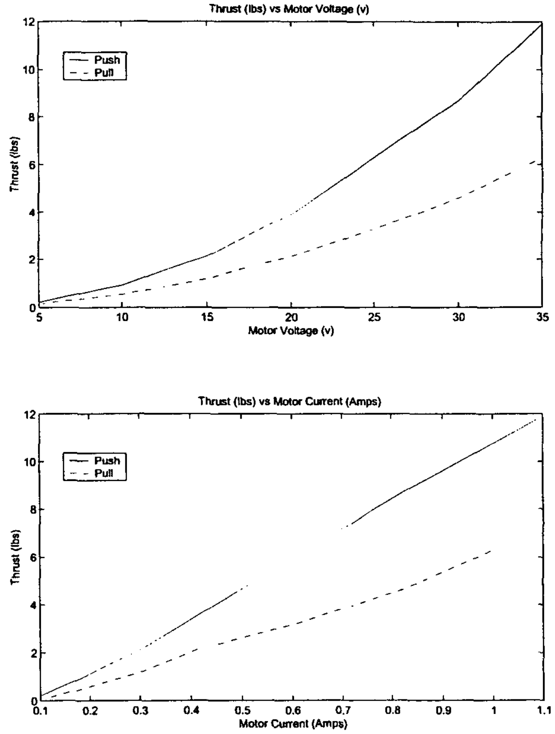

Fig. 3. Bollard test results for the thruster, both pushing and pulling

To estimate the performance of the thruster while in motion the load cell assembly was attached to a moving carriage which can be velocity controlled. By measuring the thrust, motor voltage, motor current and carriage speed, the efficiency as a function of speed can be calculated. The plot in figure 4 shows the most efficient speed for the thruster moving through the water to be approximately 70 cm/sec. To change this efficient speed several different propellers will be tested.

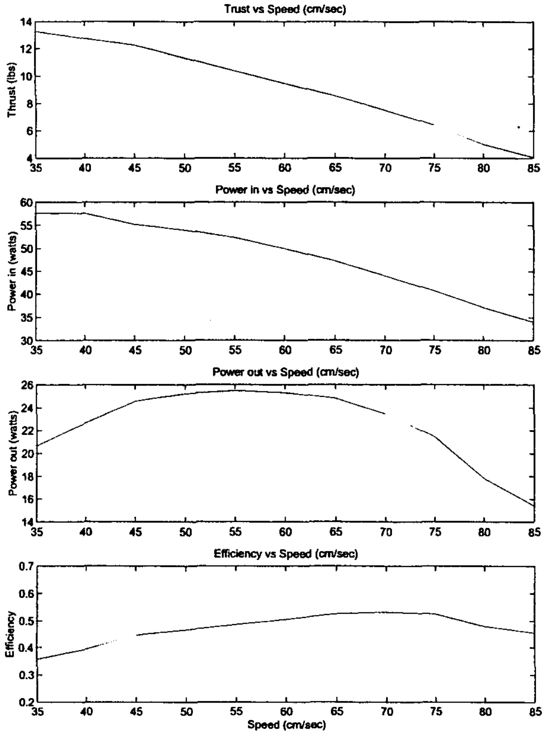

Fig. 4. Performance of the thruster for moving tow carriage experiments , motor voltage 40v

The thruster control scheme will use two separate controllers. Based on the vehicle's operating regime and dynamics the overall vehicle controller will command a specific thrust for each thruster. Using the approximately linear relation between motor current and thrust, a local thrust control loop for each motor will monitor the winding current and adjust the motor voltage to produce the commanded thrust.

This control scheme allows the transient dynamics of each truster to be handled by the local current control loops. Information gathered from the moving thruster tests will be used to specify the desired command for each thruster motor as a function of the vehicle motion. Although this control architecture prohibits more advanced control techniques from combating the time varying and nonlinear behavior of the thrusters, this approach should prove to be robust and free of the complexity of more sophisticated methods.

V. POWER SYSTEMS

The vehicle carries a compact 2 kWh battery pack that represents 25% of the vehicle dry weight. The pack consists of 126 high-energy density Li-ion secondary D cells and the necessary circuitry for monitoring and recharging without opening the housing. Experience with other AUVs shows that battery handling and recharging has a large impact on turn-around time and system reliability.

Power is distributed along buses according to voltage levels and signal quality. The hotel load, including processing stack, navigation sensors (compass, gyro, depth and LBL) and motor controls is 15 W. Main propulsion (2 Thrusters) at 1 m/s represents a load of 100 W. Surveying sensors and navigation (camera, strobe, scanning sonar and doppler) represent another 50 W. Total power is under 200 W, leaving some room for additional power requirements while retaining a ten hour endurance and a theoretical range of 36 km.

VI. SOFTWARE ARCHITECTURE

The main computing element of the vehicle will be Pentium II PC-104 stack running a Linux operating system. The main computer will interface with all other devices and sensors through serial communication. The computer will run a 5 Hertz control cycle which includes; reading sensors, logging sensor data, referencing a mission script, calculating control variables and issuing actuator commands.

The CCD camera for imaging will be connected to its own digitizing board. This board communicates with the main processing stack for image storage and optional realtime processing . The Imagenix will run at approximately at 10 Hz and it's range and bearing information will be time-stamped and stored for corregistration with navigation data.

The main software environment will be built around a mission script format. The mission script will consist of a connected sequence of modular tasks. Each task description contains the relevant sensor information and desired vehicle behavior. Each task also contains a set of cues that will cause the task to be ended. These cues may signal the completion of the task or that a higher priority situation has arisen. A simple task would be a transit from one position inside an LBL net to another position. The task requires the navigation sensors to be active and the data collection sensors to remain off. The task would be completed when the vehicle moves within a specified radius of the desired position or time has expired and the vehicle was not able to make it to the second position.

VII. CONCLUSIONS

We have presented an overall view of the design and main subsystems of a new imaging AUV. Inspired by previous and parallel efforts, the guiding principal has been simplicity in design and operation. We are currently transitioning from detailed design to actual construction of the different subsystems. Vehicle trial operation should begin early in 2001.

VIII. ACKNOWLEDGEMENTS

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