Design of SHRIMP ROV for surveillance and mine sweeper

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Unmanned Underwater Vehicle (UUV) is developed for various applications from civil until military requirement. One of the most important UUV missions is surveillance including mapping of marine resources and monitoring of the sea environment to prevent the destructive activities. Underwater security becomes more crucial for the country that`s have thousands island. The study comprises the design of special Unmanned Underwater Vehicle, the SHRIMP-ROV (Remotely Operated Vehicle). This UUV has special configuration and mechanism that can be functioned as a surveillance agent (observation UUV) and as minesweeper agent. The detail idea, design background and step by step of design methods were observed in this study.

[Keywords: UUV, ROV, Surveillance, Destructive fishing, Mine sweeper]

Underwater environment creates various challenges for the manufacturers of the vehicle robotics. Underwater hydrodynamics characteristics are complex typified by couplings of motions in six degrees of freedom. UUV is characterized by streamline geometry similar to torpedo shape with low drag and powered with single propulsion unit and a number of control surfaces. This configuration however restricts the UUV capacity to hover and maneuver around the specified operation point.

The proposed UUV described in this study is designed to have the capability of underwater mapping, supervision (surveillance) and sending payload. Hydrodynamic modeling is carried out to evaluate the stability of the vehicle in the simulated environment condition. The dynamic model is developed for the purpose of design and validation of the control system. The modeling effort is motivated by a challenge anticipated in UUV navigation in the form of uncertainty in the estimation of the position of the vehicle. This factor is considered critical especially in the context of precision approach to the target and collision avoidance task. The technical configuration of the unmanned underwater vehicle prototype is described in the Table 1. Fig. 1 describes the 3D drawing of the UUV Shrimp. Fig. 2 describes the detailed components of the vehicle.

There are numerous factors contributing to the success or failure of UUV development. Potential loss of an unmanned underwater robot is considered intolerable and should be prevented at all cost. Step-by-step research and development is therefore taken as an approach to address challenges and high risk associated with the testing and operation of the underwater vehicles.

Numerical Simulation

Early in the design process, extensive numerical simulation will be performed to predict the dynamic and stability characteristic of the underwater vehicle. Dynamics of underwater robotic vehicles, including hydrodynamic parameter uncertainties, are highly nonlinear, coupled, and time varying. Several

<table>
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<tr>
<th>Table 1—Specification SHRIMP ROV</th>
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<tbody>
<tr>
<td>Dimension (LxWxH)</td>
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<tr>
<td>Weight on air</td>
</tr>
<tr>
<td>Operating Depth</td>
</tr>
<tr>
<td>Max Speed</td>
</tr>
</tbody>
</table>

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modeling and system identification techniques for underwater robotic vehicles proposed by researchers will be investigated. The available commercial software such as Fluent will be utilized to help understand the complex behavior of underwater environment.

Hydrodynamics Modeling

The hydrodynamic modeling will be conducted as an essential part of developing mathematical model for unmanned underwater vehicle using Newton-Euler equation for a body moving in six degrees of freedom. The hydrodynamics forces effect not only the vehicle fuselage but also all the manipulators attached to the vehicle. The effect of thruster dynamics on the vehicle also becomes significant, especially when the vehicle has slow and fine motion. Therefore, accurate modeling and verification by simulation are required steps in the design process. The developed mathematical model will be subsequently used for control system design, analysis and simulation for the UUVs.

Control Design and Simulation

Major facts that make it difficult to control underwater robots include: the highly nonlinear, time-varying dynamic behavior of the robot; uncertainties in hydrodynamic coefficients; the higher order and redundant structure when the manipulator is attached; disturbances by ocean currents; and changes in the centers of the gravity and buoyancy due to the manipulator motion which also disturbs the robot’s main body.

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Sensor and navigation system

One of the major challenges in developing vehicle autonomy is the availability of sensory system for guidance and navigation. Various sensors to support the vehicle mission will be tested and integrated into the vehicle system. The investigation will include optical, x-ray, acoustic imaging, and laser scanners for inspection; Doppler, sonar inertial system, and gyroscope for navigation; sonar, magnetometer, laser scanner, magnetic scanner, and chemical scanner for recovery; and force, tactile, and proximity sensors for construction. An Extended Kalman Filtering scheme will be developed to fuse measurement from different sensors. As a measure of enhancement of national competitiveness, research effort will be also focused on developing in-house underwater sensors.
Communication development and Integration
The communication with UUVs provides formidable challenges. The main approach today for through-water transmission involves acoustics in which transducers convert electrical energy into sound-waves. Since the ocean rapidly weakens the acoustic energy as the frequency is increased, relatively low frequencies are desirable for longer-range communications. The research activities will investigate the viable underwater communication system including the use of acoustic modems.

Design and Manufacturing Prototype
The design for UUVs body is guided by the CFD analysis to yield a hydrodynamically optimum configuration i.e. low-drag and maneuverability. A challenge in the design and fabrication of UUVs body is selecting the material that can endure enormous water pressure and corrosive environment. The viability of using composite material will be emphasized.

Testing and Validation
Upon the final extensive HILS, the field-testing strategy for the UUVs is an incremental testing from water-tank, pool and finally to sea-site. A series of testing will be conducted to assess the performance of the underwater vehicle designs. The first testing of prototypes will be conducted in the shallow water environment with the purpose of validating the basic control and communication system. The ultimate sea testing will be performed after repeatable successes with the preceding series of tests.

The main purpose of the CFD analysis is to extract the UUV maneuver characteristic at each operation condition. Force, moment and pressure distribution on the hull is analyzed as part of the modeling. At the stage reported in this paper, the results of the analysis are also used to guide the mechanical design of the UUV, particularly for its propulsion system.

The CFD analysis condition of the UUV Shrimp is summarized below:

1. UUV “Shrimp” performed forward and backward maneuver with 5 knots speed. (Fig. 3.)
2. UUV “Shrimp” performed up and down movement with 1 knot speed. (Fig. 4.)
3. UUV “Shrimp” performed forward maneuver with variation of angle of attack of control surface (-20 deg until +20 deg) (Fig. 5.)

The Fig. 3 reveals that to push the UUV “Shrimp” with the speed of 5 knots, the required thrust is 152.63 of N. Since UUV Shrimp is designed with two thruster configurations as shown in Fig. 1, it can be concluded that the specification for minimum thrust is about 76 N for each thruster. Considering this requirement a thruster candidate is selected as illustrated in Fig. 6 with the specification given in Table 2.

The selected thruster in Table 2 can only push the UUV “Shrimp” with the maximum speed around 3 knots. The Fig. 7 shows that the drag generated by UUV “Shrimp” at speed around 3 knots is 49.6 N. Thus the requirement for each thruster is 49.6 N/2 = 24.81 N.

Similar idea is implemented for the selection of the thruster for vertical maneuver. Fig. 4 shows that for vertical maneuver with the speed of 1 knot the required thrust to oppose the drag is about 35 N. With single thruster configuration for vertical maneuver, the minimum requirement of thrust of thruster at 1 knot is therefore 35N. The selected thruster is given in Fig. 8 with the specification given in Table 3.

Several designs from manufacturers are briefly presented for comparative study. The proposed designs use different methods to achieve the same mission.

![Figure 3— Forward and backward maneuver CFD analysis results](image3)

![Figure 4— Vertical maneuver CFD analysis results](image4)
Table 2— Thruster for forward maneuver

Specifications

<table>
<thead>
<tr>
<th>Power</th>
<th>400 Watt</th>
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<tbody>
<tr>
<td>Rotation Speed</td>
<td>1270 rpm</td>
</tr>
<tr>
<td>Bollard Thrust</td>
<td>75 N</td>
</tr>
<tr>
<td>Thrust at speed 3 knot</td>
<td>22.9 N</td>
</tr>
<tr>
<td>Dimension</td>
<td>Ø200 mm × 350 mm</td>
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</table>

Table 3— Thruster for vertical maneuver

Specifications

<table>
<thead>
<tr>
<th>Power</th>
<th>250 watt</th>
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<tbody>
<tr>
<td>Rotation Speed</td>
<td>2000 rpm</td>
</tr>
<tr>
<td>Bollard Thrust</td>
<td>50 N</td>
</tr>
<tr>
<td>Thrust at speed 1 knot</td>
<td>35 N</td>
</tr>
<tr>
<td>Dimension</td>
<td>Ø135 mm × 300 mm</td>
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</table>
One of the mine disposal designs is SeaFox developed by Elektronik Atlas as shown in Fig. 9. The vehicle has been used both as surveillance device and as mine disposal. In mine disposal operation, the ROV is deployed for neutralizing the mine by crashing its body to the suspected object, Fig. 9. Although this operation is prohibitively expensive, it has been installed in several available minesweepers vessel in Europe. Common scenario of mine disposal operation is given in Fig. 10.

Compared with existing systems, the mine disposal scenario by using UUV Shrimp offers some benefits. The scenario is depicted in Fig. 11 where the neutralization of the mine was done by discharging certain explosives to the suspected object. In this scenario, the UUV is deployed only to discharged explosive to a certain coordinate and
maneuver away to return to the support vessel. This approach is clearly more economically attractive than one where the UUV is disposable in a single use.

One other advantage of UUV Shrimp is its payload flexibility. Using the same platform, different types of payload can be installed, including but are not limited to: • Explosives, • Magnetic noise, • Acoustic noise, • Auxiliary Power

The design and analysis of ROV Shrimp for surveillance and mine disposal mission is presented. Compared with existing system in industry, the mine disposal scenario using ROV Shrimp offers some economical and technical benefits. The operation condition of ROV for the specified mission could be satisfied by using a thruster of 250 watt capacity. Drag, lift and moment variation as function of control surface angles have been mapped as part of modelling effort and guidance for thruster selection process. The study of vehicle stability and performance in non-ideal environment including the effect of current and wake would be the future work. The investigation of high performance control system will also be conducted to achieve the most efficient maneuver control. To realize the potential benefit of the propose approach on the use of the ROV for mine disposal further study is necessary. The blast resistance of vehicle structure will be further investigated in conjunction with the prediction of safety distance after demolition.

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References