Software-In-the-Loop based Modeling and Simulation of Unmanned Semi-submersible Vehicle for Performance Verification of Autonomous Navigation

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Abstract. Since an unmanned semi-submersible is mainly used for the purpose of carrying out dangerous missions in the sea, it is possible to work in a region where it is difficult to access due to safety reasons. In this study, an USV hull design was determined using Myring hull profile, and reinforcement work was performed by designing and implementing inner stiffener member for 3D printing. In order to simulate a sea state 5.0 or more at sea, which is difficult to implement in practice, a regular and irregular wave equation was implemented in Matlab / Simulink. We performed modeling and simulation of semi-submersible simulation based on DMWorks considering the rolling motion in wave. To verify and improve unpredicted errors, we implemented a numeric and physical simulation model of the USV based on software-in-the-loop (SIL) method. This simulation allows shipbuilders to participate in new value-added markets such as engineering, procurement, construction, installation, commissioning, operation, and maintenance for the USV.

1. Introduction

In the Maritime Classification Code of the World Meteorological Organization (WMO), sea level 5.0 is the average sea level at 2.5 m to 4.0 m above sea level. If the sea level is above 5.0, offshore operation will be interrupted.

![Figure 1. 2011~2015 Monthly storm weather days](image-url)
The storm warning is announced when the wind speed of 14 m/s or more on the sea lasts more than 3 hours or when the significant wave height is expected to be more than 3 m. The number of days for the 2011~2015 monthly storm surge is 108 days based on the South Sea and East Sea in Korea as shown in Figure 1. At sea level of 30% in 1 year, it is 5.0, so there is a limit to safety navigation on board, which is increasing the need for unmanned maritime monitoring and security / surveillance missions.

As demonstrated in Figure 2, unmanned vessel is mainly used in coastal waters and polluted waters, which are difficult to access from the safety aspect of the missions carried out by the manned vessel. Long-term operations such as marine surveillance and marine surveys can minimize operational costs and crew fatigue accumulation. It is also used primarily for the purpose of carrying out dangerous missions such as search and removal of mines, infiltration operation, and operation in the tough sea. Unmanned ships are mainly used for military purposes, but recently demand for public purposes is increasing. There is still little demand for civilian use and it is mainly used for scientific purposes [1].

![Figure 2. Application area of unmanned ship [1]](image)

Unmanned vehicles that can be operated at sea are unmanned airplanes and unmanned vessel. Unmanned ships are more capable of stealthing than unmanned airplanes, and unmanned ships can be classified as unmanned surface vehicle (USV), unmanned semi-submersible vehicle (USSV) and unmanned underwater vehicle (UUV). UUV is superior to USV in terms of stabilization of the hull, but the moving speed is slower than USV. The USV has a communication environment because the communication device and the external camera are located on the water surface. Therefore, to compensate for the disadvantages of USV and UUV, the unmanned semi-submersible form is an optimized platform for performing missions in rough marine environments as illustrated in Figure 3[1].

![Figure 3. Comparison of characteristics between unmanned semi-submersible and other unmanned vehicles](image)

In this study, we design and implement a platform for autonomous operation of unmanned semi-submersible to operate in rough sea environment above 5.0 sea level. Therefore, it is aimed to
establish the environment where the hull design of the unmanned submersible and the marine environment implemented by Matlab/simulink can be visualized in three dimensions on the DMWorks(Digital Manufacturing Works), and to verify the dynamic behavior of the unmanned semi-submersible in a virtual environment.

2. Unmanned semi-submersible hull design

2.1. Basic design of Myring hull based unmanned submersible

![Myring hull profile](image)

Figure 4. Myring hull profile

The semi-submersible designed in this study was selected as a cylinder type to minimize the resistance of the fluid, and the hull type was designed by comparing it with the cylindrical type of the Myring hull type. In Figure 4, The Myring hull form is respectively determined by the following equation [2] [3] [4].

\[
\begin{align*}
\text{Stem section : } r(x) &= \frac{1}{2}d \left[ 1 - \left( \frac{x - a}{a} \right)^{\frac{1}{n}} \right] \\
\text{Middle section : } r(x) &= d \\
\text{Stern section : } r(x) &= \frac{1}{2}d - \left[ \frac{3d}{2c^2} - \frac{\tan\theta}{c} \right] (x - a - b)^2 + \left[ \frac{d}{c^3} - \frac{\tan\theta}{c^2} \right] (x - a - b)^3
\end{align*}
\]

As a result of the comparison, the average error rate of the stern was 3.08% as shown in Figure 5. Finally, the total length was determined as 1000 mm, the width was 350 mm, and the height was 300 mm.

![Myring calculation and design ship stem comparison](image)

Figure 5. Myring calculation and design ship stem comparison

In order to make the prototype of the unmanned semi-submersible, the main specifications were determined through the hydrostatic calculation and the hull form design with AVEVA Marine by referring to the main specifications and the hull form of the unmanned surface vehicle, unmanned semi-submersible and unmanned underwater vehicle[5] [6].
Table 1. Main characteristics of unmanned submersible and hydrostatic calculation result

| Division                  | Unit (mm)     |
|---------------------------|---------------|
| LOA                       | 1000          |
| B                         | 350           |
| D                         | 300           |
| Draft                     | 150           |
| Displacement Volume       | 29454281.98   |
| LCB                       | 514.182       |
| VCB                       | 89.153        |
| Block Coefficient, Cb     | 0.6545        |
| Midsection Coefficient    | 0.7835        |
| Prismatic Coefficient, Cp | 0.8354        |
| Water Plane Area          | 262949.156    |
| LCF                       | 502.952       |
| Water Plane Coefficient   | 0.8765        |
| KMT                       | 147.883       |

2.2. 3D modeling and 3D printing of unmanned semi-submersible

3D modeling was performed for 3D printing of inside and outside of the designed unmanned semi-submersible hull form. As shown in Figure 6 (a), (b) a connection path for mounting a GPS receiver and an obstacle recognition sensor are installed on the outside.

Figure 6. 3D model of unmanned semi-submersible

3. Modeling and Simulation of DMWorks based unmanned semi-submersible

We simulated the wave using the wave spectrum and implemented it in Matlab / Simulink to simulate the rolling motion of the unmanned semi-submersible which can communicate with the central server in the rough sea environment and can operate easily [7].
Table 2. Wave Definition [7]

| Division       | Wave definition                                                                 |
|----------------|--------------------------------------------------------------------------------|
| Regular wave   | \[\xi(x,y,t) = \xi \sin[(\omega t + \epsilon - kx \cos(\chi) - ky \sin(\chi))]\] |
|                | where \(\omega = \frac{2\pi}{T}\) (rad/s) : Wave frequency                   |
|                | \(k = \frac{\omega^2}{g} = \frac{2\pi}{\lambda}\) (rad/m) : Wave number       |
|                | \(\lambda = \frac{g}{2\pi}T^2 (m)\) : Wave length                          |
|                | \(c = \sqrt{\frac{g\lambda}{2\pi}} = \frac{\lambda}{T}\) (m/sec) : Phase velocity |
|                | \(\chi (rad)\) : Direction of wave                                           |
| Irregular wave | \[\xi(x,y,t) = \sum_{i=1}^{n} \xi(i) \sin(\omega(it + \epsilon(i)) - k(i)(x \cos(\chi(i)) + y \sin(\chi(i)))\] |
|                | (n : The of the harmonic wave components)                                      |

Based on Table 2, a wave block model was created as shown in Figure 7

Figure 7. Matlab/Simulink wave block model

To simulate real sea area test or model test in marine environment of 5.0 sea level or more, we constructed a rolling motion simulating platform environment of prototype based on DMworks with wave parameters of unmanned submersible as shown in Figure 8.
In order to test the simulation platform in a real-time environment, we propose an autonomous navigation simulation architecture of an unmanned semi-submersible that can operate in a rough environment by linking National Instrument Veristand, LabView Real-Time, and Phar Lap ETS with DMWorks as shown in Figure 9.

4. Conclusion
In this study, an USV hull form was determined using Myring Hull profile, and reinforcement work was performed by designing and implementing inner stiffener member for 3D printing. In order to simulate a sea state 5.0 or more at sea, which is difficult to implement in practice, a regular and irregular wave equation was implemented in Matlab / Simulink. We performed modeling of semi-submersible simulation based on DMWorks considering the rolling motion in wave.

In the near future, we plan to conduct real-time testing based on hardware-in-the-loop and to design and implement a motion compensator to minimize the rolling motion.

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