Proceedings of Engineering and Technology Innovation, vol. 9, 2018, pp. 17 - 24

A Study on Unmanned Surface Vehicle Combined with Remotely Operated Vehicle System

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Received 02 March 2018; received in revised form 04 May 2018; accepted 02 July 2018

Abstract

In this paper, we proposed a new hybrid system that combines an USV and the ROV. It is designed to overcome the cumulative navigation error and the battery problem for long time operation. The USV is connected to the underwater robot with a tether cable that enables GPS data transmission and stable power supply. In addition, by installing a winch system on the USV, it is possible to move and to retrieve the ROV for long distance travel and for depth control. The ROV equipped with underwater sensors which can acquire underwater image capture and undersea topography information and can transmit it to the land through the USV in real time was designed. Line-of-sight navigation and dynamic positioning algorithm were studied for the USV to perform autonomous navigation and keeping-position while ROV is doing underwater operations. Good performance of the USV was verified by simulation and real sea experiment using the developed hybrid USV and ROV.

Keywords: unmanned surface vehicle, USV, remotely operated vehicle, ROV, hybrid system, dynamic positioning

1. Introduction

Recently, exploration and development of marine resources have become an answer to the problem of energy shortages. Due to the nature of the marine environments, it is important to operate a underwater robot to minimize loss of life during the work. Also, the recent discovery of marine resources around the world is becoming a major issue when it comes to using limited resources in the face of energy shortages. The sea has an infinite amount of resources, but currently only some parts of the ocean are utilized. For exploiting underwater resources, underwater robot such as the autonomous underwater vehicle (AUV) is very useful and essential. In this reason, AUV platforms have been developed from abroad, such as the ISiMI and REMUS series. [1, 2]

The AUV has features of getting underwater terrain information and underwater object search. For high-speed / precision motion performance and long operation of the AUV, expensive navigation sensors and high-capacity batteries are required. In addition, in order to retrieve the information acquired under the water, the AUV should be recovered from the sea or should rise to the surface for sending the stored data through Wi-Fi or Iridium communication. ROV, on the other hand, is a submersible that is remotely controlled by cables connected to the operating system. Due to the limitation of the cable length, it is not possible to perform a wide range of surveying, but it is suitable for underwater work using manipulators and cameras.

In the case of the USV, studies have been conducted to extend mission roles by increasing the communication distance, and to expand the range of surveillance and reconnaissance missions by installing various sensors. [3] Maritime boundary,

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reconnaissance, and ocean and oceanographic topography are important tasks of unmanned aerial vehicles. In order to carry out these missions, large amounts of information obtained from cameras, radar and sonar are needed. In order to send such information to the control station in real time, a fast wireless communication speed is required. [4] Nowadays, thanks to advanced researches, the availability of USV has increased in the area of autonomous navigation and remote control and its technology is becoming more advanced. [5]

Therefore, it is necessary to develop a new concept of the platform that can receive underwater information in real time with a long operating duration and high speed performance. The concept of a new platform can be confirmed in Fig. 1. In this paper, we introduce the development of a new hybrid unmanned ship and underwater robot (HSUV) that combines AUV, ROV and USV technologies to improve existing underwater robot performance.

The hybrid USV and ROV consist of ROV, launch / recovery Winch, and USV that can move fast to a target location with the ROV mounted. The USV performs position and DP control using GPS and AHRS sensors and three thrusters, while the winch system controls the depth of the ROV.

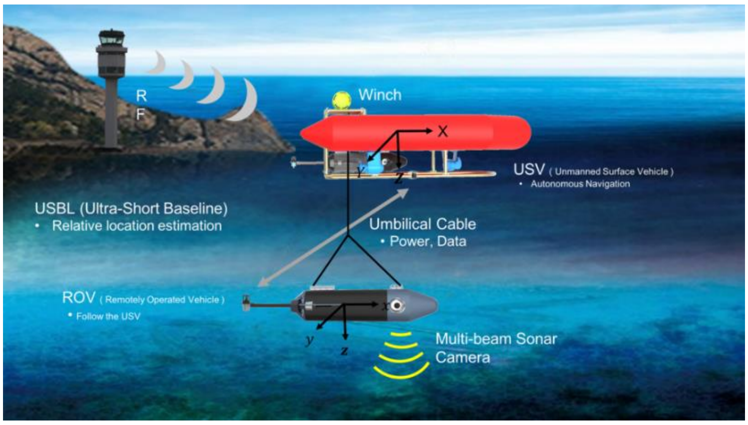

Fig. 1 Concept of USV-ROV system

The ROV is equipped with AHRS, US BL, and Depth sensors to accurately follow USV's movements and to control depth. Also equipped with an underwater search camera and a multi-beam sensor, underwater information can be transmitted to the ground in real time. By controlling the tether cable length of ROV according to the water depth, scanning seabed exploration can be conducted with a constant resolution even if the depth changes. This concept is shown in Fig. 2.

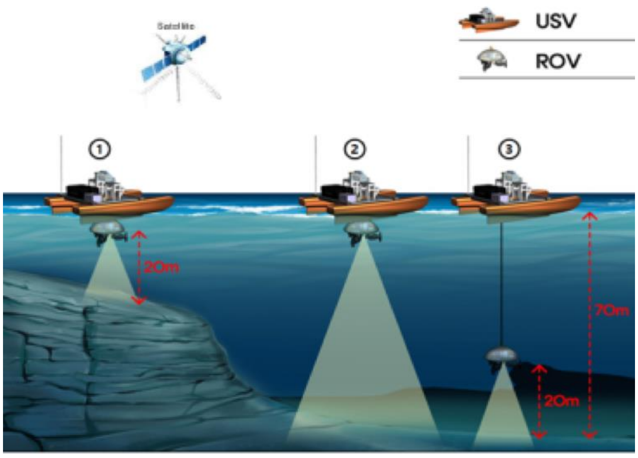

Fig. 2 Concept of ROV Depth Control

The position of USV is determined based on GPS, and the relative position between USV and ROV is measured using USBL mounted on the ROV. The exact position of the ROV can be calculated by GPS and USBL data. As a result, more accurate positioning results can be obtained at a lower cost than USV / AUV combined platforms. [6]

2. USV System

2.1. Structure of USV

The USV platform studied in this paper uses a rubber boat as a hull considering shock and buoyancy. Three propellers are installed to control yaw and surge motion. Two propellers are mounted horizontally in the direction of the track and one propeller is mounted vertically to perform dynamic positioning functions. In addition, a docking station for ROV docking was installed under the hull.

The communication between USV and operator is made up of RF and LTE, and the communication between USV and ROV is made by serial communication through tether cable.

The structure is shown in Fig. 3. Use GPS to measure the position of USV, and use USBL to determine the relative position between ROV and USB. In addition, real-time monitoring is possible on the ground with RF communication. The USV consists of the main control system for position, attitude and speed control, a winch system for controlling the depth of ROV, and a communication system for data transmission / reception and ROV control.

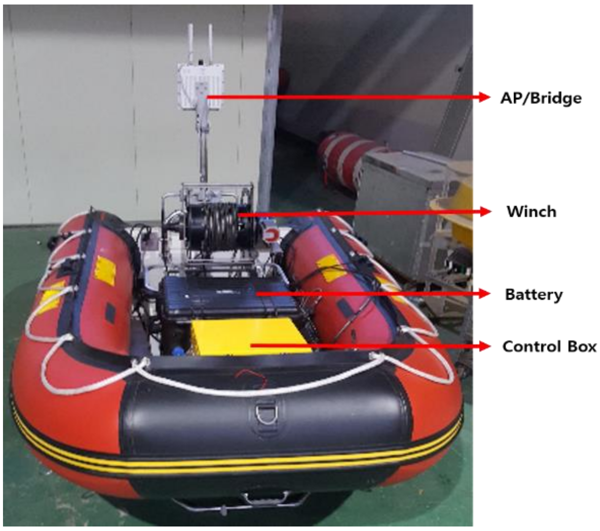

Fig. 3 System structure of Hybrid system

2.2. Control system of USV

The control system consists of a control system for the USV operation and a winch control system for controlling the depth of the ROV. This will be described in detail as follows.

The USV's control system is shown in Fig. 4. AHRS and GPS sensor is used to control USV position and attitude and control the path by LOS method. ROV is controlled by serial communication through tether cable. Also, by installing a winch system, it is possible to control the depth of the ROV and to Launch and Recover the ROV.

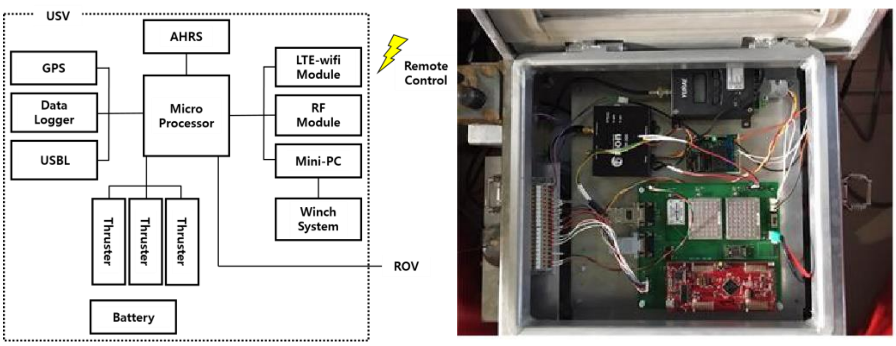

Fig. 4 Control system of USV

2.3. Winch control system

The winch system was installed in USV to control the depth of ROV steadily. A tether cable is designed with stainless steel wire to withstand the tension caused by the weight and wave of ROV. Fig. 5 shows the winch control system mounted on the USV.

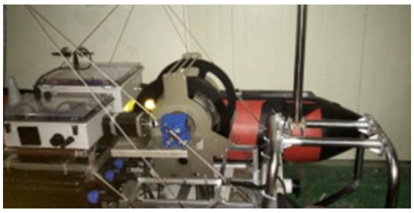

Fig. 5 Winch system

The control system for driving the winch system is shown in Fig. 6. The main controller receives ROV depth information and controls the rotation of the winch to reach the target depth.

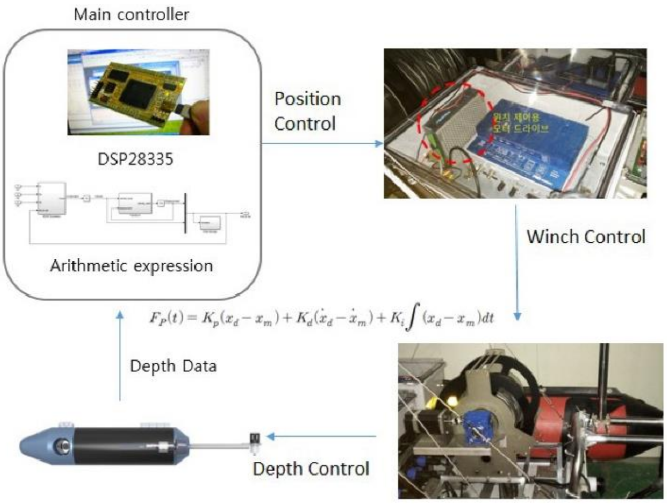

Fig. 6 Winch control system

3. Design of ROV

The ROV is mounted under the hull to acquire underwater data. ROV is connected with USV to receives GPS information and power, transmits image information acquired by underwater camera and multi-beam sensor, undersea topography information, and position and attitude information of underwater robot.

3.1. ROV structure

The shape of ROV is shown in Fig. 7. By using three thrusters, it can control surge, sway and yaw.

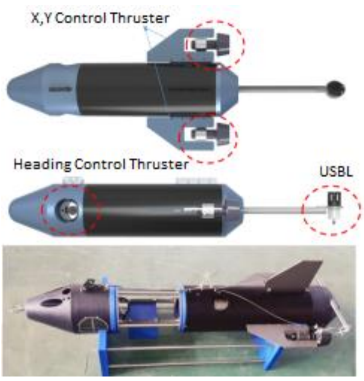

Fig. 7 3D modeling & feature of ROV

ROV is designed to be docked to USV to reduce power consumption and fluid resistance when moving. ROV is docked shown as Fig. 8.

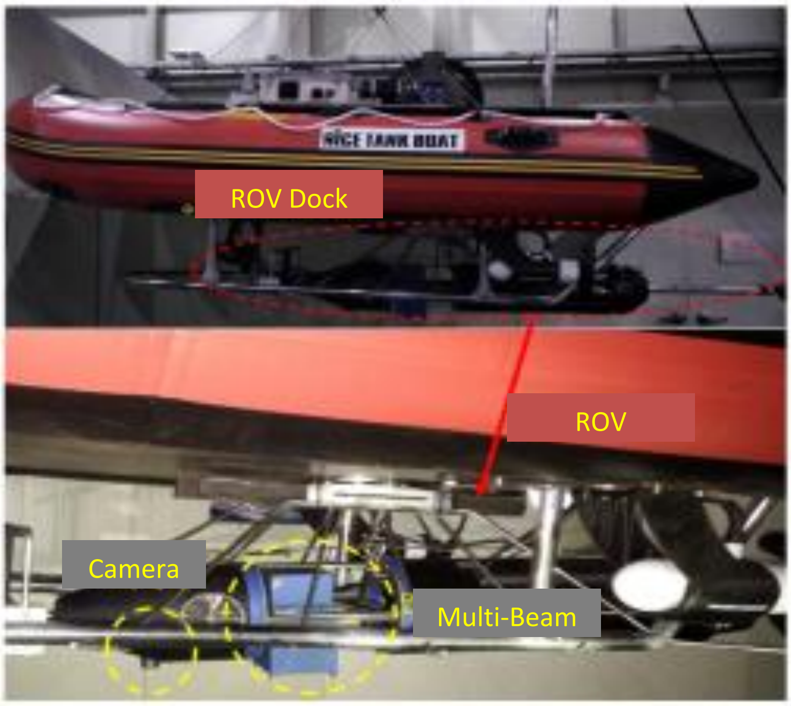

Fig. 8 Feature of docking station

3.2. Control system of ROV

The ROV control system is based on a DSP control board. The DSP performs ROV driving, sensor data acquisition, arithmetic processing, and communication functions. The control system ROV is equipped with USBL, Depth and AHRS sensors to determine position and orientation. Acquired images and undersea features were processed with a separate embedded PC to improve storage and processing efficiency. Fig. 9 shows the ROV control system.

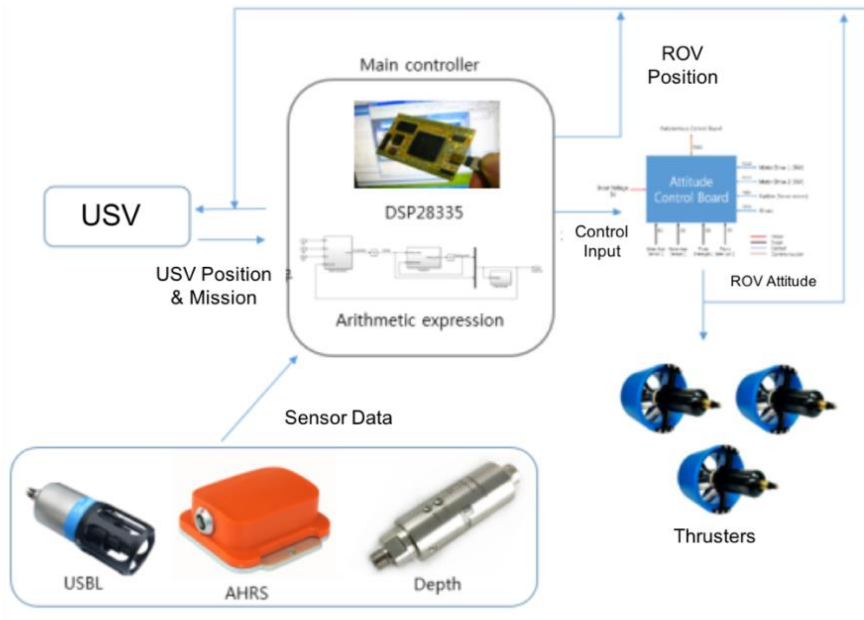

Fig. 9 Control system of ROV

Fig. 10 is a control program designed for control of USV and ROV simultaneously. USV GPS position information is displayed on the bottom right corner, and ROV relative position is displayed on the bottom center. In addition, the attitude of USV and ROV can be displayed in 3D, and the waypoint and control gain can be set.

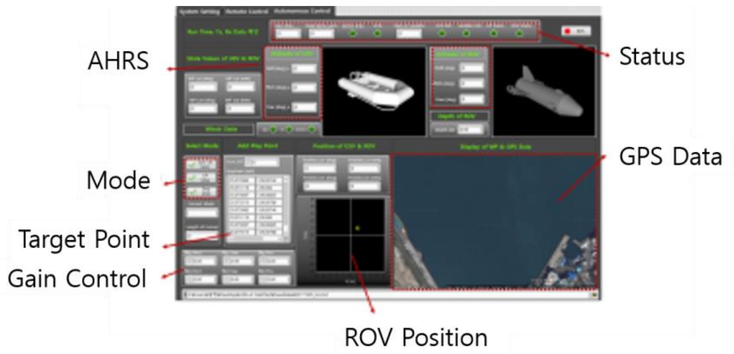

Fig. 10 Control console program of HSUV

4. Hybrid USV-ROV System

4.1. Control system of USV-ROV hybrid system

The control system of HSUV is shown in Fig. 11. RF communication can be used to transfer route path and winch control commands to the USV or to receive position and attitude information of the hybrid system. Underwater images and undersea topography information can be received using LTE network and monitored in real time.

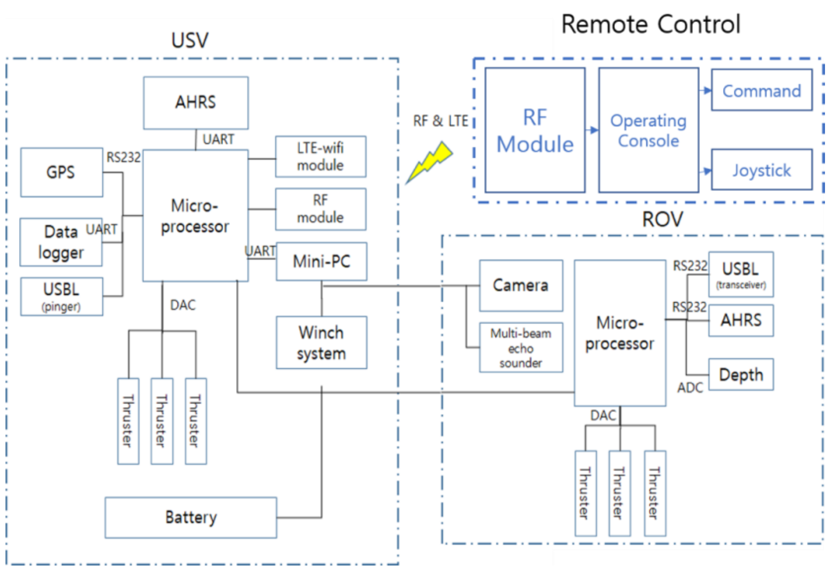

Fig. 11 Control system of USV-ROV hybrid system

5. Performance of Hybrid System

5.1. Navigation algorithm

The USV must be able to move to a specific location and maintain its position for underwater work. Therefore, the navigation algorithm was developed for calculates the target heading of the USV and move to the target point by using the LOS (Line of Sight) method.

$$\psi_U = tan^{-1}\left[\frac{Y_k - Y(t)}{X_k - X(t)}\right]$$
$$\rho^2(t) = [X_k - X(t)]^2 + [Y_k - Y(t)]^2 < \rho_c^2 \tag{1}$$

In (1), [Y (t), X (t)] symbolizes the position of the unmanned line, and [X_k, Y_k] symbolizes the position of the waypoint. ρ_c symbolizes the radius of the waypoint. If the USV enters the radius of the waypoint, the heading angle is calculated to the X and Y positions of the USV using Equation 1 so that the target does not deviate from the radius. Also, it was designed so as not to deviate from the predetermined radius by using the PID controller as in Equation 2 and Equation 3 .

$$u_{position} = K_p \cdot e_{position} + K_i \cdot \int e_{position} dt + K_d \cdot \dot{e}_{position} \tag{2}$$

$$u_{\psi} = K_p \cdot e_{\psi} + K_i \cdot \int e_{\psi} dt + K_d \cdot \dot{e}_{\psi} \tag{3}$$

5.2. Performance test of navigation

Fig. 12 is the test result of the waypoint driving performance of the HSUV when the ROV is launched by 0.5m. The darkly marked point is the target point, and the softly marked is the actual travel path of the Hybrid System. It seems to be pushed in one direction due to disturbance such as wind, but it returned to the target point within a short time.

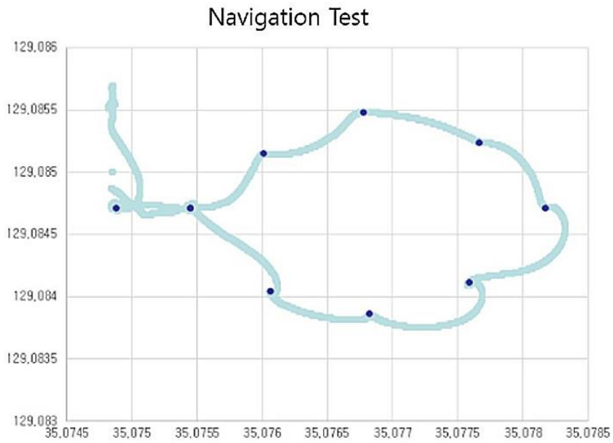

Fig. 12 Test result of waypoint navigation test

6. Conclusions

In this paper, we proposed a new hybrid system that combines the USV and the ROV to overcome the cumulative navigation error problem of the underwater robot and the battery problem for long time operation. The USV is connected to the underwater robot with a tether cable that enables GPS data transmission and stable power supply. The ROV equipped with underwater sensors which can acquire underwater image capture and undersea topography information and can transmit it to the land through the USV in real time was constructed.

Line-of-sight navigation and dynamic positioning algorithm were developed for the USV to perform autonomous navigation and keeping-position with ROV's underwater operations. Performance test of the USV was done at real sea using the developed hybrid USV-ROV. The navigation algorithm was applied using the GPS and AHRS sensor for tracking the trajectory composed of ten circular way-points. Despite the disturbance waves and tides, the HSUV performed tracking all the waypoints successfully. The experimental results showed that the maximum distance between HSUV and waypoints was under 1.5m, which is the radius of the waypoint and the position Error between USV and ROV was under 1.5m, according to USBL data. Depth error of ROV was about 0.5m, which is considered to be occurred by waves.

Acknowledgement

This research was supported by Unmanned Vehicles Advanced Core Technology Research and Development Program through the National Research Foundation of Korea(NRF), Unmanned Vehicle Advanced Research Center(UVARC) funded by the Ministry of Science and ICT, the Republic of Korea(No. 2017M1B3A1A03094006), and this research is a part of the project National Research Foundation of Korea (NRF-2016R1A2B4011875)

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