Design and Implementation of HEU Heading for the 2018 Maritime RobotX Challenge

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***Abstract*—The Maritime RobotX Challenge is a capstone robotics competition. Harbin Engineering University has built the first generation of the HEU Heading, which is highly reliable, readily upgradable and maintain, to participate in the competition. The HEU Heading is equipped with high-precision sensors such as LIDAR, CAMERA, GPS, TCM, etc. The data of these sensors can reflect the state of the vehicle and sense the environment around the vehicle. The path planning algorithm obtains these data, obtains the target from the mission tracker, and then decides the movement of the vehicle. In order to facilitate the use of operators, the HEU Heading interface has remote control and autonomous mode, and can be switched at any time. After more than two months of In-Water testing, the HEU Heading proved to be able to better complete the task of the competition.**

I. Introduction

A. Team Overview

The HEU Heading team of Harbin Engineering University consists of two instructors, one doctoral student and eight master students. The main research direction of the instructor is the control and planning of unmanned boats. In the aspect of unmanned boats, the instructor has solid theoretical basis and rich practical experience. The main research directions of the students in the team are ASV (Autonomous Surface Vehicle) control, planning, navigation, perception and so on. In the previous study, besides the study of theoretical knowledge, students have corresponding experience of science creation practice. Through the design, installation and testing of ASV, the team has a better understanding of the ASV field. The team is shown in figure 1.

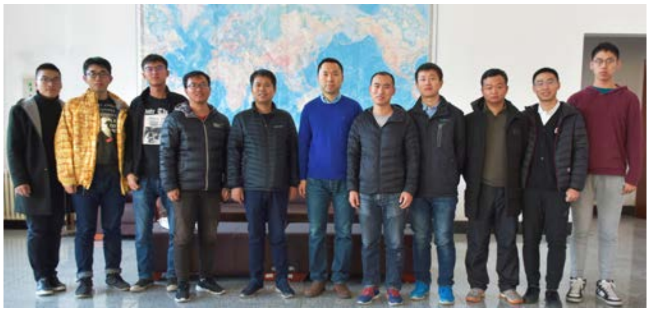

Figure 1. The HEU Heading Team

B. Vehicle Overview

The HEU Heading is designed to be highly reliable and easy to update, in order to meet the mission requirements. Under payload tray, two drawers are symmetrically installed, which has the following advantages: First, there is a lot of space in the two drawers, the new equipment can be directly placed in the drawer, and the overall structure does not need to be redesigned. Second, a large number of equipments are placed under payload tray, the center of gravity of the vehicle is reduced, which is conducive to the performance of the vehicle. Third, drawers can be pulled out and self locked to facilitate installation and commissioning of equipment. Fourth, drawers are installed under payload tray, payload tray can shield sunshine and rainwater, equipment will not be exposed to sunlight or rainwater immersion, prolong the service life of equipment. In order to further improve the reliability of the vehicle in high temperature environment, fans are installed at corresponding positions.

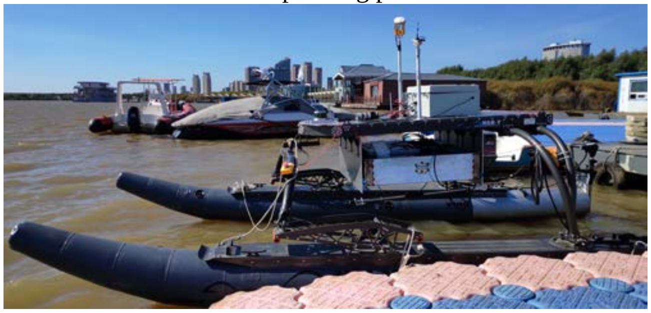

Figure 2. The HEU Heading

C. Software Architecture

Software onboard Heading is broken into individual process modules. These modules execute in parallel and communicate asynchronously. The software architecture is shown in Figure 3.

The Mission Planner aggregates data from various modules and determines the best strategy to complete the mission according to current vehicle state. It communicates the target location to the Path Planner and the objective to the Behavior Planner. The Path Planner calculates the optimal path to the target location. The Behavior Planner plans to the sequence of the behavior which to complete the objective and the behavior including: station keeping, direction keeping, path following, rotation and so on. The function of each module is discussed in Vehicle Design.

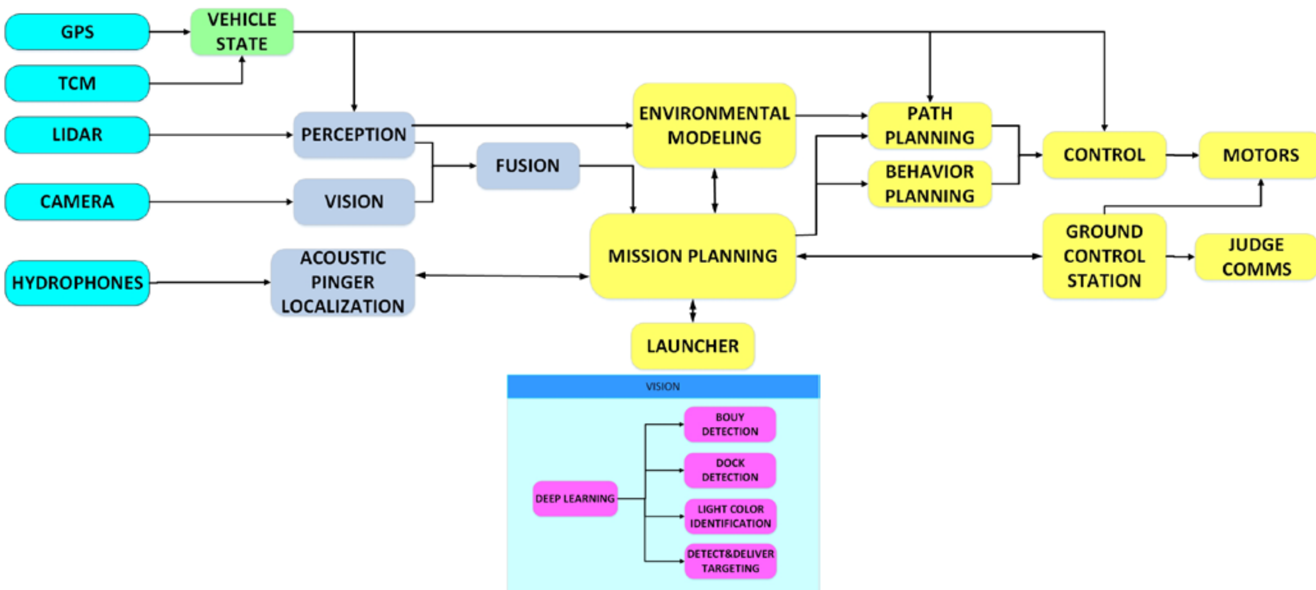

Figure 3. Software Architecture of the HEU Heading

D. Organization

Section II explains the design strategy of the vehicle. Section III discusses some methods to use on the vehicle. Section IV presents simulation and test results. Section V details summary and future prospects of the HEU Heading.

II. DESIGN STRATEGY

The HEU Heading took only eight months to design, build, test and accomplish tasks. Its original intention is not only to complete the competition task, but also as an extensible platform to complete more complex tasks.

For the perspective of the reliability and maintainability, the hardware system adopts a modular design scheme. The hardware system of the platform is divided into eight subsystems during design and production process and they are called: Power Center, Communication Center, Condition Perception, Object Perception, Control Center, Propulsion System, Ball Launcher and Ground Base. The relationship of this subsystems is shown in Figure 4.

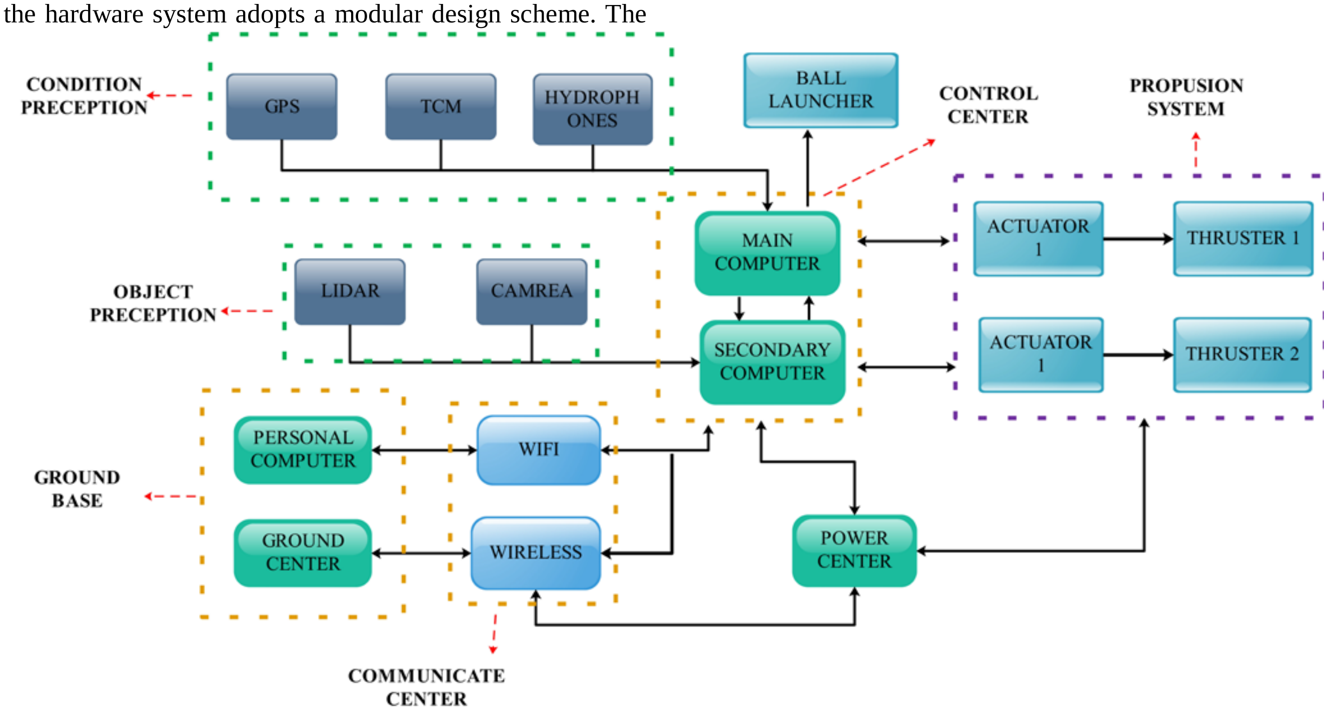

Figure 4. Hardware Overview of the HEU Heading

A. Power Center

The Power Center is responsible for the power management of the whole hardware system. It can communicate with the ground base by wireless to execute operator instruction, or it can independently monitor the condition of each subsystem to judge whether dangerous situation will happen and automatically cut off the power in time and send message to Ground Base.

B. Communication Center

In the Communication Center, the wireless, which has a high-reliability and working in a range of 2 km, and the WIFI with high transmission rate are used to connect the platform with the ground. This not only enables team members to develop and debug the software system more efficiently, but also improve the reliability of remote operation to avoid dangerous.

C. Perception System

The perception system includes a condition perception system consisting of GPS, TCM, hydrophones and an object perception system consisting of lidar and camera. In the consideration of computation speed, platform has two industrial computers, one for the main program and the other for the camera and lidar.

D. Propulsion System

The propulsion system consists of two thrusters with their corresponding actuators. In the first experiment, we found our pervious thrusters, each providing 60 pounds of thrust, showed terrible maneuverability on wave condition, so after experimenting, the thruster has been upgraded. The upgraded thruster provides a thrust of 120 pounds per unit. The actuators can receive the thrust distribution signal through the serial port, and then drive the propeller to perform the corresponding action. The unmanned boat is steered by propeller stagger.

E. Ball Launcher

The ball launcher of the platform consists of a ball feeding device and an aiming pan which could achieve a horizontal angle of 180° and a vertical 90° aiming, also it can control the shooting distance with the control of power. Most parts of the ball launcher are produced by 3D printing technology.

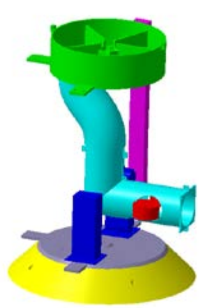

Figure 5. Ball Launcher

F. Task Perception

The goal of the Task Perception group is to identify features necessary to complete competition tasks, such as shape and color of docking symbols. The color and position of the buoy need to be got in some tasks. But vision can only get the color of the buoy and the radar can only get the position of the buoy. Therefore, a method to fusion the vision and perception were explored. In terms of vision, data of objects such as buoys and docking symbols at different time periods and different angles are collected, and training is carried out through deep learning to increase the reliability and stability of identification in different environments.

G. Environment modeling & path planning

Because the obstacles in the task of Avoid Obstacles are relatively small, path planning need to be accurate, and the accuracy and stability of environmental modeling will have an important impact on the accuracy of path planning. The grid is used to represent the environment model. Because there may be an error in the position of the obstacle detected by the perception, the probability of appearance of the obstacle is calculated to determine whether the obstacle is identified in the environment model, which improves the accuracy of the environment modeling stability.

The path planning algorithm adopts the changed velocity obstacle method which is originally used for dynamic collision avoidance. If the speed of the dynamic obstacles is zero, it can be applied to the task of Avoid Obstacles.

H. Ground Systems

Providing an open-air experimental site that is closest to the competition environment will facilitate the smooth running of the experiment, which requires the provision of obstacles, buoys of various colors, a light buoy and other targets. Due to geographical and financial constraints, the above targets are produced by ourselves. During the production process, standard parts and readily available materials are used while ensuring that the target is durable, recyclable, and low cost. For example, common wood boards, foams, etc. are used to make buoys that can change color, and common black yoga balls are used as obstacles. After experimental tests, these targets are strong and durable, ensuring the smooth progress of the experiment.

Figure 6. Buoys and Obstacles in the Find Totems task

III. VEHICLE DESIGN

The HEU Heading encounters many problems in the construction and testing phase. By constantly replacing new hardware and adopting different software algorithms, it solves the problems and completes tasks step by step. The following is a detailed description of the methods and algorithms used in the test of the vehicle.

A. Mission planner

The Mission Tracker module handles the high-level decision making necessary to accomplish the required tasks. The mission planner obtains the navigation and perception information required to complete the mission from the vehicle state module, the fusion module and the Acoustic pinger localization module, and calculates the target location where the ASV will go and the strategy for completing the mission. It communicates the target location to the path planner and the strategy to the behavior planner. At the same time, it communicates the vehicle state and the mission state to ground control station.

B. Path planner and behavior planner

The path planner obtains ASV current position from the vehicle state module and the target location from the mission planner, and plans the optimal path to the target location according to the obstacles identified in the current environment model. Due to the limited range of perception, obstacles in the environmental model may change during navigation, so the path planner needs real-time planning.

The behavior planner takes corresponding actions which are based on the mission strategy. For example, when ASV performs the task of Entrance and Exit Gates, it needs to sail to the front of the gates first, and then keep direction and keep station to determine the position of pinger.

C. Path following

The path following algorithm of the USV consists of two parts: yaw angle controller and speed controller.

In the yaw angle control part, the USV will receive the route point given from the planner and then calculate the current error angle of yaw combining with current state information received from state perception system. To make this error angle converge to zero, we have both tested PID controller and S plane controller in simulation and experiment, and finally we found the S plane controller perform better than PID controller.

The modified form of S plane controller used in our platform is shown as followed:

$$Np = K_{N_P}\left(\frac{2}{1+e^{(-k_1\varphi_E - k_2 a_E)}} - 1\right) + k_3 I_E$$

Where K_{N_P} is the output amplitude parameter, k_1, k_2, k_3 respectively is the parameter of proportion, differentiation and integration. φ_E is the yaw error, I_E is the integral of yaw error and a_E is the yaw speed.

Due to the speed could not be sensed accurately , An algorithm of look-up table based on experiment is used to control the speed of USV.

D. Camera Perception and Classification

In terms of target detection, the HEU Heading use the target detection method of deep learning. According to the popular mainstream algorithms, mainly by Faster-RCNN, YOLO, SSD, etc, according to the requirements of the competition task, the HEU Heading must ensure the highest possible target detection accuracy, Faster-RCNN has the greatest advantage in this regard, the HEU Heading chose to use Faster-RCNN detection. This platform is equipped with the industrial camera (VCXG-25M.I) based on the Gige protocol of the German Baumer company, which can rely on Gigabit network to transmit pictures and videos.

Figure 7. VCXG-25M.I camera

First of all, the HEU Heading team made the water surface detection props model in the competition area, including red, green, blue, white, black and yellow buoys, green, different colors of different shapes of the screen, LED. The props of the color-changing lamp, the water obstacle ball; then the HEU Heading put these props models into the water, fix them with a similar anchoring method, and use the camera on the unmanned boat to collect data in multiple directions; the HEU Heading get the images of the collected props. After the data, the annotation tool is used for manual labeling. About 1000 labels are used for each category to generate a VOC format data set suitable for the Faster-RCNN target detection. The Faster-RCNN target detection program is modified to train the input data set. View the Loss and MAP to find the optimal target detection model; modify the Faster-RCNN target detection program to detect the camera input image in real time, and perform real-time detection; finally print out the image to detect the type and location information of the target, and transmit Task planning for the console.

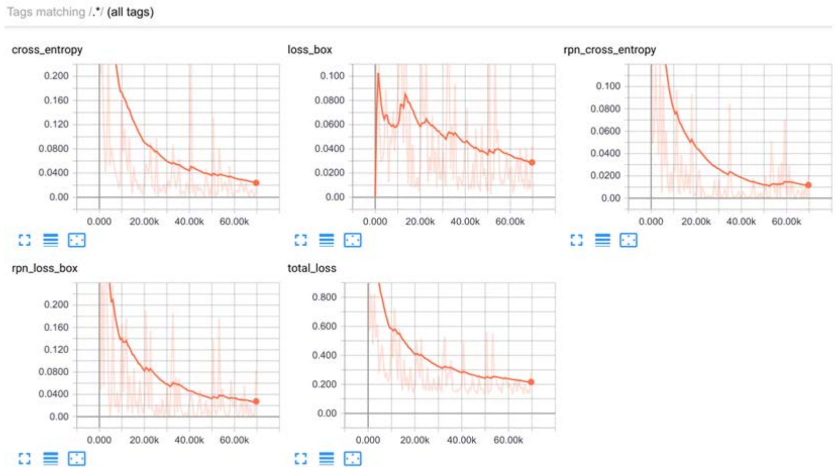

Figure 8. Training Model Process Loss Curve Change

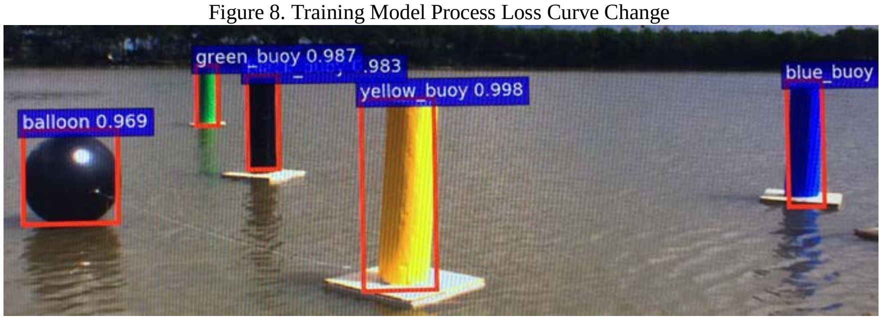

Figure 9. Buoys and Obstacles by Faster-RCNN Object Detection

E. LIDAR Object Detection and Classification

The VLP-16 laser radar mounted on the bow is used to obtain the point cloud information on the surface of the water, and then the point cloud information is processed as follows.

First, the filter is used to remove all scattered data points in the input point cloud that do not meet the clustering requirements. Due to the particularity of the water surface environment and the influence of the shore objects when the unmanned boat is near the shore, the point cloud density distribution obtained by the lidar scan is not uniform. The point cloud data in the water environment is more sparse and there are scattered interference points. This will cause interference to point cloud feature recognition and point cloud clustering, resulting in target missed detection or misdetection.

Then point cloud data is input into Kd-Tree to simplify the calculation, and the target object is segmented using Euclidean clustering. The feature points are extracted and the three-dimensional points in the depth point cloud image are projected to the two-dimensional image coordinate system. By searching for the neighboring points in the Kd-Tree and dividing the distance from a certain point to other neighboring points, the filtered point cloud is segmented to obtain a plurality of individual objects. This gives the exact position information of the object. The point cloud image detected with lidar is as shown.

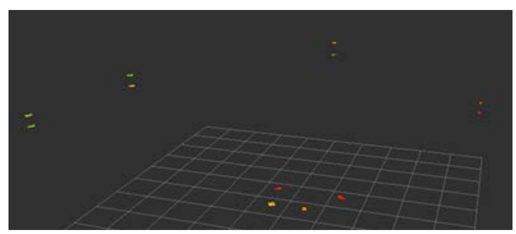

Figure 10. Buoys by LIDAR Object Detection

Finally, by synthesizing the information obtained by the radar and the information obtained by the camera, the accurate type and position information of the surface object can be obtained, and the information is transmitted to the planning part through TCP network communication.

F. Acoustic Sensor Processing

The USV is equipped with the RHSA-30 hydrophone on each of the left and right side. The positional relationship is converted according to the time when the sound wave from the pinger reaches the hydrophone. It is the key to judge the positional relationship that the delay difference of the hydrophone can be effectively obtained. Considering that the actual underwater environment has relatively small signal-to-noise, the adaptive filtering method is used to filter the signal. The filtering effect is as follows:

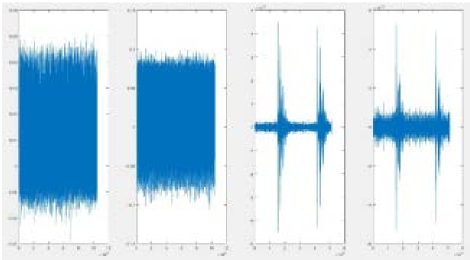

Figure 11. Before and After Filtering of Two Hydrophone Signals

Adjust the actual parameters to optimize the filtering effect. The delay difference can be obtained by performing envelope and leading edge detection on the filtered signal. It is realized by MATLAB, and the delay difference is sent to the lower computer main program through the TCP network communication protocol.

G. *Monitoring and Reporting*

The ground station is designed to: monitor the current state of the vehicle, change the current mode of Autonomous Maritime System(AMS), communicate with Technical Director(TD), and act as a remote control processing center.

There is always the need to change the content of the ground station program during the field experiment, In order to make the design of ground station stable and flexible, Team HEU Heading use the bottom-up design method to reconstruct the ground station into four modules.

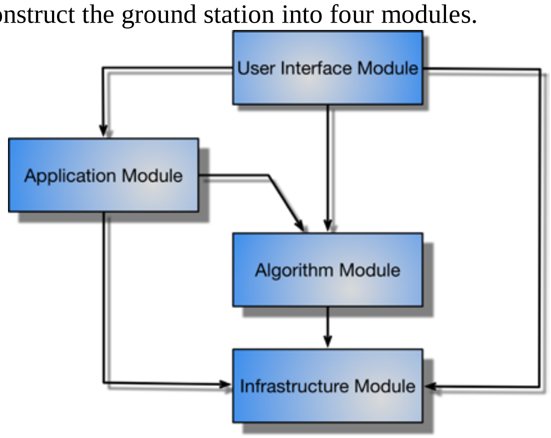

Figure 12. The Ground Station's Software Architecture

1)Infrastructure Module includes: Initialization of communication equipment, such as socket, serial port. Transformation of decimal, hexadecimal and ASCII.

2)Algorithm Module includes: Analysis of data protocol. Data encapsulation. Method of data flow, e.g., how to accept data with variable numbers.

3)Application Module include: Data sending and receiving. Using of socket and serial port. The timer, etc.

4)User Interface Module displays the status of the mission objectives along with investigating vehicle and sensor status.

At the beginning, simultaneous communication is adopted for the communication between the ground station and AMS, and sometimes AMS fails to respond, this is more frequent when there are other USV, the reason may be that the message is blocked, or received from other USV. To solve this problem, Team HEU Heading adopt responsive communication, instead of simultaneous communication, while encapsulating data, i.e., add communication protocol.

In the case of acting as a remote control processing center, the ground station receives the hexadecimal data from the handle, which is processed through data analysis, and then sent to AMS. The difficulty is that the thrust is frequently changed and sometimes the range is very large, which causes great damage to the drive plate. Even in the field experiment, the drive plate is burnt out because the thrust range is too large and frequent. So a cumulative method is used to send data about the thrust. i.e., when the thrust suddenly rises from 20 to 50, send 30, 40, 50 to the beat instead of 20, 50.

IV. EXPERIMENTAL RESULTS

The HEU Heading use MATLAB & Simulink to build up a simulation model for path following algorithm and the simulation result shows this algorithm is applicable. It also has achieved good tracking effect during experiment.The result showed in Fig 13 is the tracking result of a circle in simulation. The experiment result is showed in Fig 14.

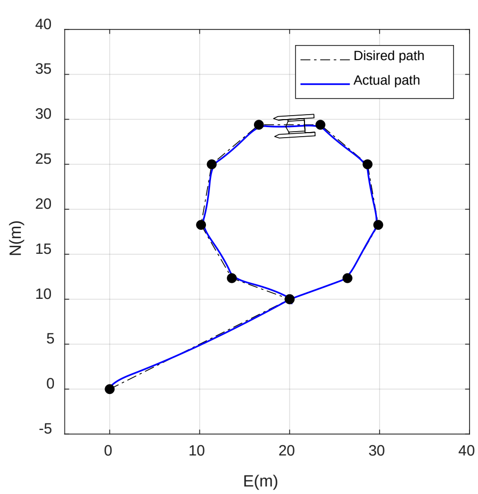

Fig 13. Simulation Result of Tracking a Circle

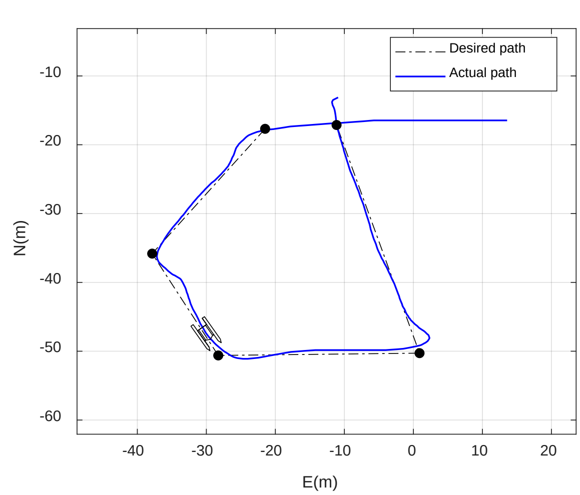

Fig 14. Experiment Result of Path Following

V. CONCLUSION AND FUTURE WORK

The HEU Heading, as a platform with high reliability, easy updating and maintenance, is designed not only to complete the task of the 2018 Maritime RobotX Challenge, but also to become a platform for ASV in-depth research. The HEU Heading uses many innovative design concepts and methods to solve various problems encountered. In terms of hardware, many of sensors are first used, e.g., lidar and hydrophone. The overall scheme of hardware adopts modular design, which is easy to replace damaged hardware and expand when adding new hardware. In terms of software, the HEU Heading has many frontier algorithms, e.g., Faster-RCNN and the changed velocity obstacle method.

After more than two months of In-Water Experiments, the HEU Heading can only accomplish some tasks because the task is very difficult, and the success rate of the task can only be maintained at about 80%.

In future work, the HEU Heading needs to improve overall stability, processing speed, accuracy, and increase the number of tasks completed. In the aspect of simulation, it is necessary to form a systematic simulation platform to improve efficiency and reduce test time. Due to the limitation of time, funds and personnel, AUV was not manufactured in this competition. In the next stage, an AUV should be manufactured so that it can cooperate with ASV.

VI. ACKNOWLEDGEMENTS

The HEU Heading Team would like to acknowledge Harbin Engineering University, College of Shipbuilding Engineering, Lenovo(US), the RobotX sponsors, AUVSI, DGX, and those individuals who have helped us in this project.

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VIII. APPENDIX

A. Situational Awareness

A significant challenge to adoption of unmanned systems is user trust. Users need to know the reliability of the unmanned system, the status of the ASV, and the tasks the system performs. The HEU Heading considers what measures should be taken for ASV in dangerous situations if the system detects the danger itself? And if the system itself does not detect danger, what measures should be taken?

First of all, on the HEU Heading, ASV uses passive mode to send information. If the system security program detects that ASV does not receive OCS information, the time is more than 10 seconds and the ASV is out of connection, the system will stop the propeller immediately and continue to send location information to the outside world, waiting for rescue.

Then in the ASV test process, the propeller is sometimes entangled by fishing nets and other debris. The HEU Heading drive device is equipped with a current sensor. When the current exceeds the rated current, the system will automatically cut off the power supply of the propeller and send warning information to OCS.

Finally, when the ASV is in danger, but its own system has not detected, people can directly cut off the power supply of the propeller or the total power supply of the system by the status parameters on the OCS. OCS interface is shown in Figures 15.

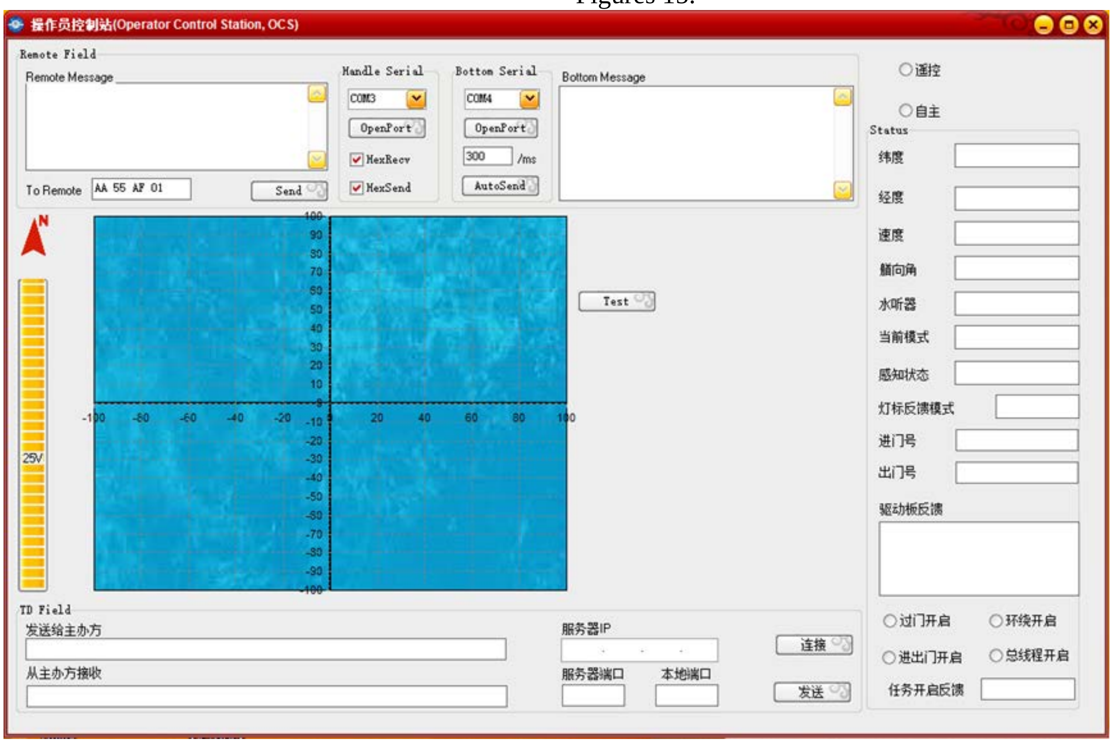

Fig 15. On the right side of the OCS interface is the state feedback of ASV, including position information, navigation information, propeller information and mission information. In order to visualize the status information of ASV, a real-time location map is established on the left side of the OCS interface. The buttons of ASV remote control and autonomous mode are on the upper right of OCS, which can be switched in real time.