Design and Concept of the Unmanned Surface Vehicle "Horizon Blue"

Team Horizon Blue

Kentaro Goto, Masaaki Sugimoto, Hideo Yasue, Katsuya Shiotsubo, Aki Tomoda, Kyoichi Jinno, Fumiya Fujimori

Abstract - Horizon Blue is an Unmanned Surface Vehicle (USV) designed to compete in the 2014 Maritime RobotX Challenge hosted by Association for Unmanned Vehicle Systems (AUVSI). Team Horizon Blue is a team organized by students from the department of engineering of the University of Tokyo. The concept of the USV Horizon Blue was decided by the member's skills. The senior and experienced members had broad experience in mechanical designing, so we decided to make our original propulsion system as the main feature of this USV. The development of the control system was kept simple by using LabVIEW, graphical programming software, considering the inexperienced members. However the propulsion system did not meet the shipping deadline, therefore making it difficult to compete in the challenge. Team Horizon Blue has also made an effort in fund raising activities and succeeded in getting support from 7 companies and a few individuals.

1. Introduction

Team Horizon Blue is a club organized by students of the Faculty of Engineering of the University of Tokyo in November 2013. The logo of our team is shown in Fig. 1.

Fig. 1. Team logo

Our supervisor is Associate Professor Hideaki Murayama from the Department of Systems Innovation. Being informed about the Maritime RobotX Challenge from Associate Professor Murayama in July 2013, we started preparing to participate in the competition. The aim of team Horizon Blue is not only participating in the Maritime RobotX Challenge, but also making innovative products. The present situation of the manufacturing industry of Japan can be cited as the background of this aim. We have to say that the presence of Japanese manufacturing companies in the international market has become little compared to the economic growth period called Japanese post-war economic miracle. However we believe that this does not mean that the technology of Japan has declined. Japanese technology is still internationally competent, but needs to be integrated and leaded to further development. Therefore Team Horizon Blue will foster students with the capability to integrate various technologies. In order to do so, the top priority of our team is to constantly stimulate young members by the hand of senior and graduate members. We also have three philosophies for our activities.

1. Learning cross-sectional and practical knowledge

The members will experience various aspects of producing such as scheduling, designing, building, testing, analyzing and also raising funds. This knowledge is valuable since they cannot be gained from desk studies.

2. Consistently challenging innovative approaches

We value innovative approaches more than imitation, even if it fails.

3. To foster young talents to lead society

We will keep on making efforts to become engineers that can contribute to society.

2. Technical Approach

2.1. Concepts and Decision Process

The two main concepts of our technical approach are as below.

1. Building original high power azimuth thrusters.

2. To develop a comparatively simple controlling system by the hands of the inexperienced members.

Our team's technical approach was decided considering the team members' skills. We decided to put an emphasis on the mechanical system since the senior members had broad experience in designing and building machines. As for the electronic system, inexperienced members were in charge so we aimed for a comparatively simple development. One of our team's features is that many alumni have cooperated with us as advisors. The advisors are experienced in both software and hardware development so the team members are able to learn from them. We believe that our technical approach is unique and efficient in the long span, considering the subsequent competitions.

2.2 Mechanical Design

2.2.1. Weight Distribution

The maximum payload of the WAM-V is 136 kg. After considering the necessary weight of the control system and the battery, the remaining payload was distributed to the thruster. This is because the vehicle is faster and easier to control when the thrust force is strong. Roughly 20 % of the payload was distributed to the control system, 25 % to the battery and 55 % to the thruster. The battery's weight is approximately 34 kg, and the capacity is 3 kWh. On the other hand, the two thrusters can be equipped with a motor which has a rated output of 12 kW and a maximum output of 40 kW (one minute rate) at the current weight distribution. So the rated output will sum up to 24 kW, which shows that the battery will be used up in eight minutes of rated output. As for the maximum output the one minute rated 40x2 kW output can be used for two and a half time. However we think this balance of battery and thruster is adequate for this competition. There are two reasons. First, the time limit of the competition is 30 minutes but considering the task’s character, the vehicle will not need thrust force all the time. Second, we thought that the capability of accelerating time-to-time is important. For this year's competition we decided to set the total weight up to the payload but in the future we need to consider a lighter system. We also tried to develop heavy and strong thruster in this initial competition because it is manufacturable only by the senior members. In the long span, it would be easier to make thrusters light and the output smaller for the future members.

2.2.2. Specially Designed Propulsion System

The senior members are experienced in mechanical designing, so we designed our original azimuth thruster shown in Fig. 2. An azimuth thruster is a thruster that can rotate its propellant pod 360 degrees, and can control thrust force. One thruster will be mounted on the rear side of each hull. As the main power, we use ME1115 motor (Motenergy Inc.). This motor is an axial flux type PM motor which has a stator on both sides of its rotor. Its weight is 16 kg, the rated output 12 kW, the maximum output 40 kW (one minute rate), and the maximum rotating speed 5000 rpm [1]. As the inverter Gen4-Size4-450A (SEVCON) will be used. This inverter will be in a waterproof box that will be partly submerged in the sea, therefore will be directly cooled by the seawater. The propellant pod is a BLV640NM50S-3 motor unit (Oriental Motor Co.). It will alter its direction through V belts. A resolver of Tamagawa Seiki Co. will be used to detect the propellant pod's orientation. The thruster weighs more than 30kg so we are considering adding floats to the rear side of the thruster. We also designed it waterproof. We put oil seals on the sliding surfaces. The use of this azimuth thruster is not limited to the WAM-V, and applicable to inflatable boats, RIB and various marine robots. In addition to its high power, its quiet operation by electric motor and the 360 degree rotatable thrust force are the main features of this thruster. We are interviewing people in various fields to find the best way to apply this thruster. We have been designing and building this thruster since April, but unfortunately could not meet the shipping deadline. The cause is our failure to making an appropriate estimation of time and money when we started designing.

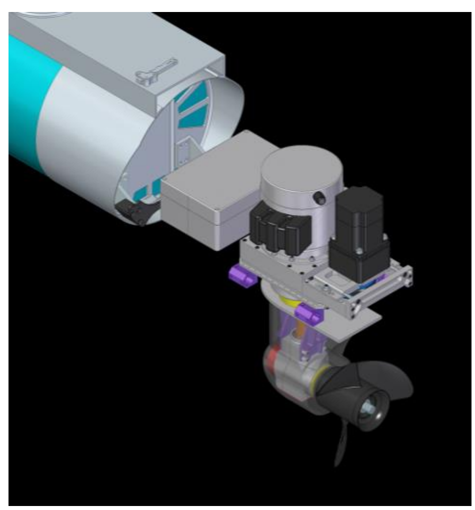

Fig. 2. Thruster

2.2.3. LFP Battery

We chose phosphoric acid iron lithium battery (LFP battery) as the main power of the thrusters. LFP battery is a type of lithium ion battery and although its specific weight is bigger than lithium polymer battery, it has lower risk of explosion and burning. So it does not need a solid case and when compared by its weight per mass it has the same level of efficiency as the lithium polymer battery. This year we mounted two modules of 48V30Ah $LiFePO_4$ (O'Cell Technology Co., Shenzhen, China) in parallel. The discharge rate of this module is 1 C, the maximum discharge rate (5 sec rate) is 2 C, so the two thrusters' output will be approximately rated 3 kW (6 kW at maximum) [2]. In the future we will aim to purchase a battery which has a maximum discharge rate of more than 10C and is as safe as the current one. Also our team has been interested in liquid organic chemical hydride fuel cell. Liquid chemical organic hydride fuel cell is a type of fuel cell that uses organic solvent to store hydrogen, and uses hydrogen taken out of the solvent using catalyzer. Currently we are not able to build an original power source due to the limitation of fund, facility and skill, so we would like to challenge it in the future.

2.2.4. Application of 3D Printer

In order to compose the control system, we needed to fix a few components to the WAM-V. We utilized the 3D printer to make the components. In this paper we will introduce the two components we've finished building.

The laser range finder (LRF) mount is shown in Fig. 3. It swings the LRF vertically. It was designed to be fixed under the platform of the WAM-V. The reason the mount swings is to prevent losing sight of objects due to the vehicles tremor or the height of the object. By the power of one motor the three LRF can be swung from -10 degrees to +5 degrees at the frequency of 4 Hz. In addition, the range of angle and center position can be adjusted. We used the 3D printer to make the nylon part of the LRF mount. Both the LRF and the LRF mount are designed to be waterproof.

Fig. 3. LRF mount

We've also made a camera mount for manual control shown in Fig. 4. This is a mount for the cameras that we will be using when controlling the WAM-V manually. By using two brushless RS-405CB servos (Futaba Co.) the camera rotate both vertically and horizontally. We used 3D printer to make ABS parts such as camera stays. To make it water-resistant, we put the whole component in an acrylic cylinder case.

Fig. 4. Camera mount

2.3. Control System

2.3.1. Overview

The control system of our team is based on National Instrument hardware, multiple sensors, LabVIEW software and Windows PC. The overview is shown in Fig. 5.

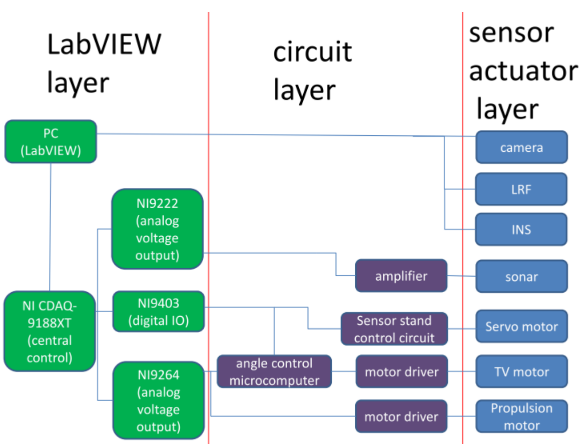

Fig. 5. Control System Overview

2.3.2. National Instrument Hardware

NI c-DAQ9178 is an 8-Slot USB Chassis that connects various devices to the PC. We used three I/O modules that connect to the chassis of c-DAQ: NI 9222, NI 9264, and NI 9403 as shown in Fig. 6. The NI 9222 is a simultaneous analog input module that has four channels and was used to get the input from the hydrophone. The NI 9264 is an analog output module and the NI 9403 is a bidirectional digital I/O module. These two were used to connect thrusters, actuator, and other sensors that cannot be connected to the PC by USB port or Ethernet.

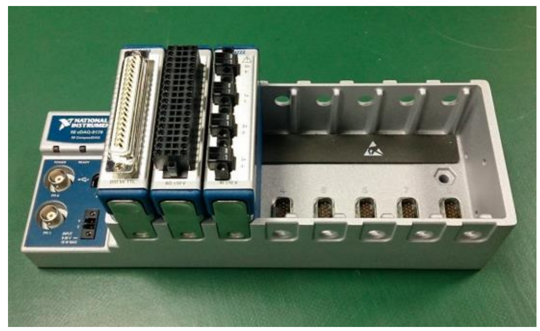

Fig. 6. NI9222, NI9264, and NI9403 installed in c-DAQ9178

2.3.3. Sensors

There are four main sensors in our control system: LRF, camera, INS and hydrophone.

For the LRF we used three UTM-30LX-EWs (Hokuyo Automatic Co.) shown in Fig. 7. The LRF has scanning angle range of 270 degree, angular resolution capability of 0.25 degree, detecting distance from 0.1 to 30 m. The LRF can be connected to the PC through Ethernet. Two LRF may seem adequate since it can scan 270 degree. However we decided to use three because when only two LRF is used the vertical range will be small at the lateral sides even using the LRF mount. [3]

Fig. 7. LRF [3]

For the camera we used seven HDR-AS100VR action cameras (SONY) shown in Fig. 8. One of the seven cameras will be used for manual control as explained above. The other six cameras will be divided into two sets of three. One set will be placed at the same angle as three LRFs at the same height as the LRFs. The other set will be placed on a mast that will be fixed on the platform. It will also be placed at the same angle as LRFs and will show a higher point of view. The cameras' image will be outputted through HDMI, so we used a device that will convert them into USB. The image will be inputted to LabVIEW and then be processed. Simultaneous processing of multiple camera images was not necessary, so we used a HDMI switching device that can be controlled from the PC. So we used one camera at a time in our image processing program.

Fig. 8. Action Cam [4]

As for the INS we will use an original one made by one of our advisors shown in Fig. 9. ADIS16488 (three axis acceleration sensor, gyro sensor, geomagnetic sensor, barometric altimeter) and LS20031 (GPS Receiver) is mounted on the INS's substrate. The data acquired by the sensors will be integrated using extended Kalman filter and will output the orientation, velocity and position to the PC. By integrating the inertial sensor's data at 100 Hz and updating the position by the GPS at 10 Hz, we will have an adequate accuracy for the tasks of this competition.

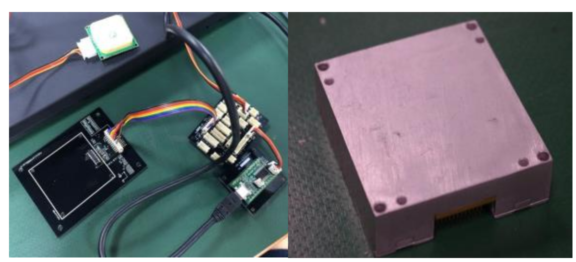

Fig. 9. INS

For the sonar system we used four H1a Hydrophones (Aquarian Audio) and composed linear array sonar. The acquired data will be amplified using PA3 Hydrophone Preamp (Aquarian Audio) and sent to the PC through c-DAQ9178. The hydrophones are placed in straight line as shown in the Fig. 10 at the interval of 3 cm. The data can be acquired at the frequency of 250 kHz, and the half width of directivity is 34 degrees when the incoming wave is 25 kHz. By beam-forming the sonar system will output the direction of the sound source to LabVIEW.

Fig. 10. Hydrophone array

2.3.4. LabVIEW

LabVIEW is graphical programming software that enabled us to develop various applications. Although LabVIEW is not widely used in Japan, we chose to use it because the graphical programming would be easier for the inexperienced members. Also LabVIEW has rich samples that we can refer to, which made our program development faster and easier. This year we have to admit that the program is not completed to a level to control the WAM-V due to the limited test environment. The biggest difficulty was that the propulsion system could not be built by deadline and we could not test the algorithm with the WAM-V. However we have been putting efforts in studying the fundamentals of relevant fields such as image-processing, signal processing and control theory. Moreover we broke down the functions necessary to clear the task, and made modules of program. Some of the programs are shown in Fig. 11 and Fig. 12. We have learnt how to process the data acquired from the four sensors, so we believe that the only thing left is testing the algorithm with WAM-V.

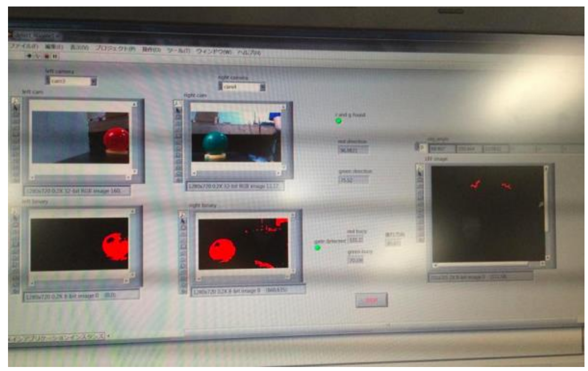

Fig. 11. Color detecting by camera (left) and Object detecting by LRF (Right)

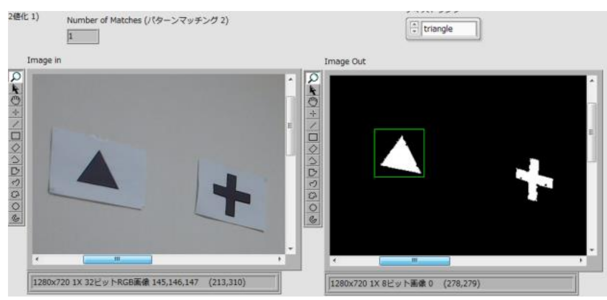

Fig. 12. Pattern matching program

2.4. Testing

From the beginning we estimated that the shake down of WAM-V would be just before the competition, and there would be little time to test the WAM-V. So we decided to make a prototype of the WAM-V and test our programs with it until the WAM-V is ready. The prototype boat was made of Styrofoam and was glued by architectural adhesion bond. It is a catamaran boat 1200 mm long and 1000 mm wide. It is mounted with two azimuth thrusters on the rear end. We mounted the PC and the sensors on the boat, and tested our programs at the towing tank of the University of Tokyo.

As for the WAM-V we found a good testing place at Kasumigaura, Ibaraki. There is an airport for hydroplane owned and administered by Piccolo air works. There is a slope leading to the water surface and is suitable for lowering the boat into the sea. The waves are also quiet and suitable for testing. We also purchased a rubber boat to support the WAM-V during tests. The F15CEHP outboard motor was supplied from Yamaha Motor. The model of the rubber boat is JEX-340 (JOY CRAFT) with six seats, 730kg payload [5]. Two of our team members got a license to operate small boats.

3. Collaboration

Our team is organized and managed completely by students. In April 2014 our team Horizon Blue became one of the official clubs of the University of Tokyo. Our supervisor is associate professor Murayama from the department of Systems Innovation. The support from the University of Tokyo is only the facilities, so all funds and devices were covered by individual or company supporting us. We will introduce our sponsors below.

AUVSI Foundation

The host of this competition and supplied WAM-V and fund to us. We have been greatly supported throughout the competition. Our team will do our best to cooperate with the management of the competition.

Yamaha Motor Co.

Yamaha Motor is a company that makes motorbikes, marine products and snowmobiles and many other transporting vehicles which is headquartered in Shizuoka Prefecture, Japan. Yamaha Motor is our team's main sponsor and supplied fund, outboard motor for the test supporting rubber boat and propellers for the WAM-V's thruster. The model of the outboard motor is F15CEHP and its displacement is 362 cm^3, has two cylinders, weighs 61 kg and has the maximum output of 11 kW. The model of the propeller is 688-45930-02-00 and 6L6-45930-01-00. They are both made of stainless-steel and their diameter is 13 inch, the pitch 17 inch and their rotational direction are right and left. This propeller was initially made for an outboard motor of Yamaha Motor (model F115B/FL115B) which has the maximum output of 84.6 kW, so it is oversize for the WAM-V. However this model was the smallest model which had left rotating type, so we decided to use this at a low rotating speed. In addition to these support, we got technical support and opportunities to communicate with the engineers. [6]

SONY

Sony is a company headquartered in Tokyo, and mainly makes products like TV, audio and video, semiconductor. Sony has supported us by supplying us eight HDR-AS100VR action cameras and a HMZ-T3 head mount display. The action cameras will be mounted on WAM-V and also be used for recording our activity. The head mount display will be used when we are manually controlling the WAM-V. We also got a chance to talk about a spin-off project of this competition that we might do in the future. [7]

Hokuyo Automatic Co.

Hokuyo Automatic is a company headquartered in Osaka prefecture, and mainly makes optical data transmission devices, sensors, auto counters and automatic doors. Hokuyo has supported us by supplying three UTM-30LX-EW model LRFs to us. [8]

Hamano Products

Hamano Products is a company headquartered in Tokyo, which undertakes metal processing. They undertook our thruster's components cutting operation. Despite of their effort the deadline and the cutting price exceeded our estimation. Since it was our first time to outsource the operation, we could not make an appropriate estimation. In the future we would like to make use of this experience and design the mechanics at an earlier stage. [9]

ZMP

ZMP is a Robotic venture company headquartered in Tokyo. They mainly produce developing platform for next generation cars, and builds robots for academic and researching use. They gave us technical advice and also introduced us companies that could help us. We hope we can collaborate more in the future since their field is very similar to our interests. [10]

Piccolo Air Works

Piccolo Air Works is a company that is headquartered in Ibaraki prefecture. They produce aircrafts, and develop electronic devices. They possess a hangar at the lakeside of Kasumigaura, and manage the Piccolo air harbor. The Piccolo air harbor was originally used by the air force as a practice site. We decided to use this place since there is a slope leading to the water that is suitable for lowering the WAM-V to the lake.

Individual Sponsors and Graduate Members

A few individual gave us monetary support, and their names are published on our website. One of our team's features is that many alumni had cooperated with the team activity. These graduate members are the same generation as the senior members and most of them work in venture companies and electronic manufacturing companies. Since the team's office is located in a share office near the campus of the University of Tokyo, we have strong connection with the venture companies near the university.

4. Conclusion

Horizon Blue is an official maker's club of the University of Tokyo. Students from the faculty of engineering can learn how to apply their knowledge learnt at school with the help of graduate members. Our activities were completely organized by the hands of students.

We have been preparing for the competition, according to our technical approach: designing of original high power azimuth thrusters and developing simple control system by using LabVIEW. Unfortunately USV Horizon Blue could not be completed to a competent level due to the delay of propulsion system making. However, in the process of preparing for the competition we were able to enhance our skills and find companies that support us. We will keep our activities going after this competition, and would definitely be ready for the next competition.

5. References

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