Journal Paper of Intelligent Marine Vehicle Innovation Team

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***Abstract*—this paper will introduce a newly designed Autonomous Underwater Vehicle (AUV) named NEMO II by graduate and undergraduates from School of Marine Science and Technology, Northwestern Polytechnical University (NWPU), China. Ten months has seen the process from ideas to reality. Although most of the sophisticated sensors are bought from famous companies, the mechanical system, the electrical system, the acoustic system and the control system are all designed by ourselves. NEMO II stands for the second generation product of our team, based on the previous one, NEMO I, which has won the third prize in Singapore AUV Competition (SAUVC). Higher reliability and robustness has achieved this year as well as flexible and intelligent software architecture.**

I. INTRODUCTION

The Intelligent Marine Vehicle Innovation Team was founded in April, 2015, supported by school of marine science and technology. There are about thirty excellent undergraduates and graduates, coming from fields of Mechanical Design and Manufacture, Communication Science and Technology, Navigation Guidance and Control, Acoustic Science and Technology, etc. According to specific tasks, our team be can divided into mechanical sub-team, electrical sub-team, acoustic sub-team and software sub-team.

Essential goals of our team are to broaden students' eyesight, provide them with opportunities to boost their shills and cultivate their potentials. We mainly aim at two annual world-wide competition—the SAUVC held in March and Robosub held in July. Participating in these competitions give us chances to communicate with outstanding teams from prestigious universities and institutions, which are priceless experiences for us to improve.

Generally speaking, the tasks in Robosub is much more complicated than these in SAUVC, which simulate real-world missions and demand some intervention capabilities. These tasks include visual and acoustic detection of competition elements, ranging from shape and color, navigation, obstacle avoidance, and object manipulation tasks. Each of these tasks must be completed by the vehicle independent of human control or interaction.

It really costs us a lot of energy to think up ideas to meet as many requirements as we can and to cope with a number of unexpected problems. So we have NEMO II now, which will compete in 19^{th} Robosub. It presents higher reliability more reasonable structure, and more powerful intelligence than the previous one.

II. MECHANICAL SYSTEM

A. Overview

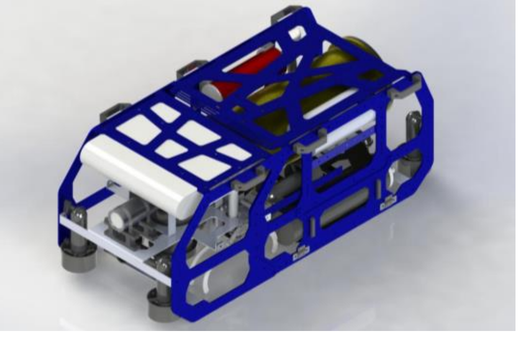

Fig 1. Overview of NEMO II

Table I

GENERAL MECHANICAL PARAMETERS OF NEMO II

Length	1020 mm
Width	400 mm
Height	380 mm
Weight	42.7 kg
Max Depth	50 m
Thruster	8 in total, including 4 for vertical motion, 2 for lateral motion, 2 for surge

B. Main Hull

The main hull, measurement of which is $510 \times \Phi 203$, is made from aluminum alloy with a PMMA end cover and the other aluminum cover. It is used to seal the electronic components and protecting them from water, as well as provide about 16 kg buoyancy.

Fig 2. Main hull of NEMO II

C. Frame

The frame, which is also made from aluminum alloy, defines the positions and orientations of each mechanical component in the vehicle, maintaining the structural integrity and rigidity of the vehicle and protecting delicate components.

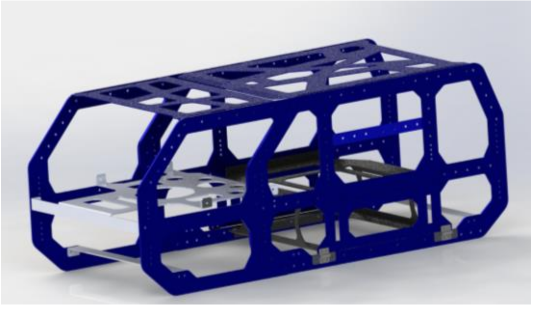

Fig 3. Frame of NEMO II

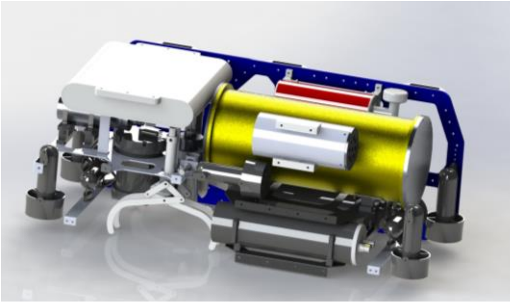

Fig 4. Left view of NEMO II without frame

Fig 5. Thruster

III. ELECTICAL SYSTEM

AUV's electrical systems provide the vehicle with power and an interface between the control sub-system and the other sensor's COTS devices. Nearly all of the printed circuit board are custom designed and populated in-house all by ourselves, and many boards contain a custom-coded microcontroller to interface with the computer.

Our AUV's electrical systems contain control units, power units, sensors units and sonar signals processing units. Because underwater acoustic signals processing is very difficult and sophisticated, so the sonar unit was separated, and implemented by a dedicated person in charge of sonar signals processing algorithms. We try to use inter-board traces, try to avoid using the wire, and this allows for improved wire management for electrical interfaces between boards inside the hull.

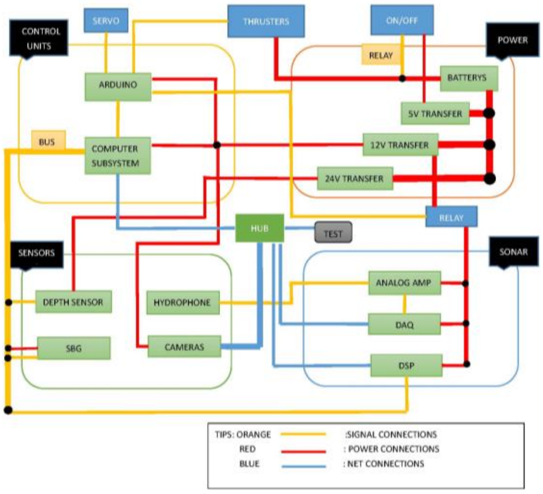

Fig 6. Block diagram of AUV's electrical systems

A. Power Units

The power to run AUV is provided by four lithium polymer batteries which give the vehicle a run time of about 6 hours. These batteries are hot-swappable, which means the vehicle can be kept running while the batteries are changed. We use the diode to control 4 are discharged simultaneously, they will all run out of power at the same time (6 hours later), and then we just need to change the batteries' hull.

The batteries supply the 24V DC power, and we made a power board to convert the voltage to 12V, 5V and 24V. We use the DC/DC converter to provide the different voltage to the electrical systems.

One new development is the addition of two bright LED strips controlled via a new relay control board.

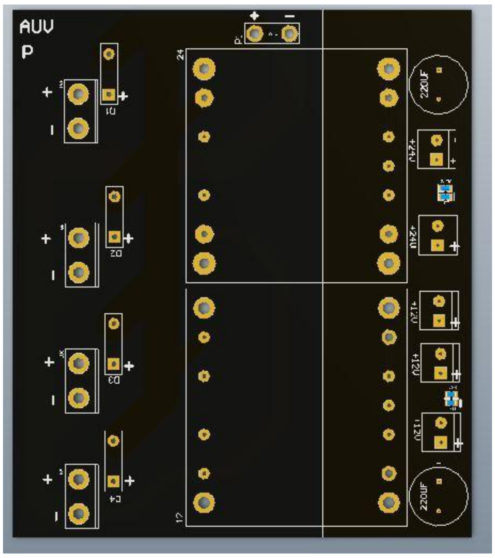

Fig 7. AUV power board

B. Communication

We use the RS-232, RS-485, RJ-45 and USB to communicate in the electrical systems, for the different communication. The serial communication is the interface between the computer and the various sensors and custom-designed boards. The RS-232 protocol was chosen because it is noise tolerant and ubiquitous, and the RJ-45 protocol was chosen because its' scalability.

C. Control Units

1. Main Control

The main control boards contain an on-board computer and an ARDUINO MEGA 2560. The Arduino receives signals from the computer and controls all the servo such as thrusters and other relays and It also provides power to the kill switch board and sends information from the kill/mission switches. The computer subsystem receives all sensors' data except the hydrophones and processing those data, then feedback the control signals to the Arduino to all servos.

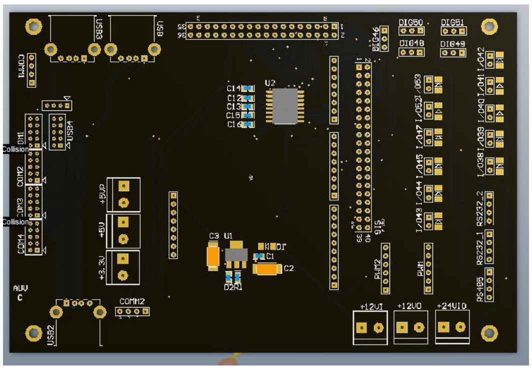

Fig 8. One costumed control board

2. Thruster Control

The thruster board drives up to eight brushed thrusters on the vehicle. They are powered through custom H-bridge configurations, and their speed is set by the computer over PWM and I/O signals. Power for the thrusters comes directly from the power board. The thruster board receives the kill signal from the actuator board, and uses hardware to halt all thrusters.

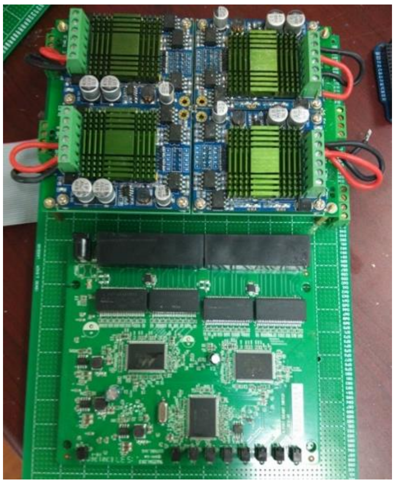

Fig 9. Actual thruster control board

D. Sonar Units

We placed hydrophones to an array, enlarge the received analog signals to 1000 times, then let signals pass the filters, and then after A/D conversion, the signals becomes digital signals, then do the digital signals processing through the DSP board.

IV. SENSORS

Sensors of NEMO II mainly contain two industry cameras, four hydrophones, an inertial measurement device SBG, a depth sensor, a Doppler Velocity Log (DVL) and some other sensors to detect the temperature and humidity in the main hull.

A. Cameras

NEMO II uses two color cameras for visual recognition and navigation tasks. These two cameras are both Allied Vision Technologies (AVT) Manta G-046C, one as forward camera and the other as downward camera.

Manta G-046C has many satisfactory advantages such as high quality and stability, a considerable number of programmable features and acceptable resolution with fast frame rate. It connects to the on-board computer with Gigabit Ethernet via a Hub, offering stable and high speed communication. Taking all these advantages into account, it may be the best choice for underwater tasks based on our present hardware conditions.

However, Manta G-046C is disabled in changing the lens' focus electrically, fixed focal length lens is considered. In order to offer a wide angle of view, we use 5 mm wide-angle lenses from Japanese company Compute. Camera and lenses are shown in Fig.

Fig 10. Manta G-046C

Fig 11. Compute 5 mm wide-angle lens

B. SBG

We choose SBG Ellipse-A as an inertial device to observe the attitude of our AUV. Ellipse-A is a small-sized high performance Attitude and Heading Reference System (AHRS). It provides Roll, Pitch, Heading, and Heave data. Ellipse Series is more accurate, more robust, and more versatile than the previous series.

Table II

SPECIFIC PARAMETERS OF ELLIPSE-A

Series	Ellipse-A AHRS
Roll & Pitch	0.2 °
Heading	1 °
Heave	10 cm
GNSS Position	-

C. Hydrophones

The hydrophone we use is Teledyne RESON Hydrophone TC4013. The TC4013 offers a usable frequency range from 1 Hz to 170 kHz and a high sensitivity relative to its size. It further-more provides uniform omnidirectional sensitivities in both horizontal and vertical planes up to high frequencies, which can receive signals from any direction.

Fig 12. Hydrophones TC4013

D. Depth Sensor

Our depth sensor is from a Chinese company MIKE, which is built for applications requiring absolute pressure measurement of liquids and gases. It is well-suited for a variety of applications across many industries.

E. Doppler Velocity Log

One new development is the addition of the DVL, we use the LinkQuest's NavQuest 300 Micro Doppler Velocity Logs (DVL). The system can measure instrument velocities relative to the bottom and instrument velocities relative to the water. The instrument velocity is derived from the Doppler shift of the received acoustic signal when an acoustic wave travels in the water.

V. ACOUTIC SYSTEM

Underwater acoustic positioning, which is laying hydrophones in a special way to receive the underwater acoustic signals, can get the position of acoustic beacon by processing the signals received. The method we use is passive sonar detection that hydrophone only receive and process the sonar signals or radiated noise to acquire parameter of a target.

The hydrophone we used is an omnidirectional transducer, which can receives signals from any direction. In the coopetition, the hydrophone are laying into cross array and the algorithm we used is phase comparison method for angle position. It’s a big challenge for us to get the position of target by laying four hydrophone in the small underwater acoustic carrying platform.

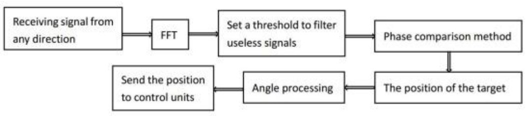

Fig 13. Flow chart of acoustics

VI. SOFTWARE

The software of NEMO II can be roughly divided into control sub-system and vision sub-system. The control sub-system is supposed to decide when to launch and when to cut off energy, how to operate maneuvering and at which to change to following tasks, based on the external and internal information that observed. The vision sub-system is designed to give the vehicle up-to-date and accurate data about the surrounding mission elements. All the programs are written in C/C++ upon the Windows 7 operating system.

A. Computer

The software on the vehicle is powered by an Intel Core i5 Boardwell ULT SoC CPU with a 32GB solid state drive (SSD). The computer is connected to the Hub through an adaptive 100/1000 Mbps Ethernet tether.

B. Control Sub-system

The software architecture of control sub-system is built upon Visual Studio MFC framework, written in C/C++. Main goal of control sub-system is to operate different thrusters with typical PID control laws, in order to reach the reference motion state calculated by specific navigation and guidance methods, based on the fused information of attitude, depth, current speed, vision and acoustics. Using the collected and filtered vehicle state data, NEMO II is able to have precise and accurate vehicle control for five degrees of freedom: surge, sway, heave, yaw and pitch. The on-board computer gives command to thrusters through a control unit, Arduino MEGA 2560. The control sub-system receives message, sends commands and deals with the calculation in different threads for the sake of efficiency. When debugging and testing, real time states of the vehicle will show in a testing window on the upper computer, which is connected with the on-board computer through an Ethernet tether.

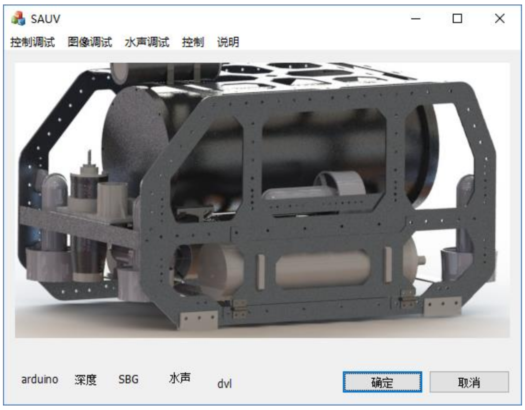

Fig 14. Index page of the testing window

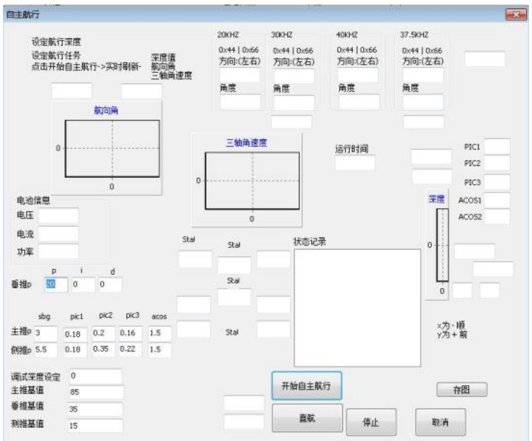

Fig 15. Parameter page of the testing window

C. Vision Sub-system

Most of the tasks in Robosub demand accurate vision position and recognition capabilities, making vision one of the most important external information sources.

All the visual information is captured through camera. Thanks to the flexibility of Manta Series, most of the common features, such as exposure, white balance, frame rate and so on can be set according to specific needs. We have programed the cameras to reach a better performance based on a number of tests and experiments.

The vision sub-system is built using OpenCV function library, which is mature and widely used in vision-processing fields, while the algorithms are designed by ourselves. Frequent and typical operations have been formed into costumed functions so that each mission can use directly.

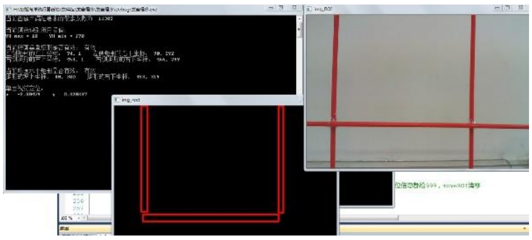

Fig 16. Recognition result of one mission

We have fused both shape and color features to raise accuracy. Mission elements are detected by a combination of edge detection, color thresholding, and contour analysis, though not all elements use every algorithm. Although relative range information cannot be extracted directly through a single frame, not like the case with binocular stereo imaging, the period of vision processing is much shorter of monocular vision, which is of great benefit to transit real-time data. In order to calculate the relative range information with only one camera, we have designed a position method based on monocular vision using geometry principle. Simulation experiments as well as real environment experiments have been implemented to certify the performance of this method.

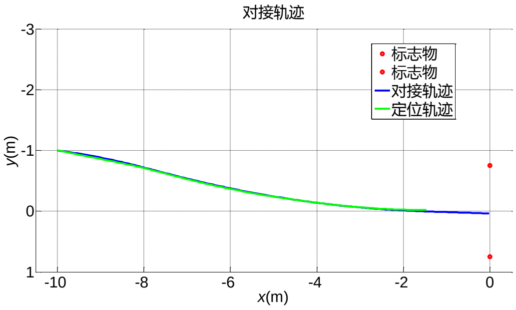

Fig 16. Certification of monocular position method, in which the green line stands for the observation and blue line stands for the trajectory of our AUV

Acknowledgment

Thanks to all the help we received from various institutions and individuals, we have made great progress since we were engaged in the design and manufacture of NEMO II. To our delight, NEMO II performed much better than we expected at the very beginning, although we decided to give up some functions we couldn't reach. It had its first autonomous run in a swimming pool of NWPU on June 18th, and testing has continued since.