NACIT: Design and Implementation of AUV Paxer

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***Abstract*—AUV Paxer is an underwater observation and operation system designed and manufactured by Northwestern Polytechnical University and Xi'an jiaye AUV Collaboration and Innovation Team(NACIT). As a matter of fact, we are a young team and it is our first time to participate the RoboSub competition. In this process, CAD Modeling is totally used on the Paxer AUV to achieve paperless design. We work closely with industry, and according to the features of the various components, different advanced manufacture techniques such as 3D printing technology, laser cutting technique, NC-Machining Technology and so on were utilized. Paxer has eight brushless DC motor propellers, and equipped sensor modules include a depth sensor, INS, a hydrophone array and two cameras equipped with wide-angle lens. The software architecture is based on Windows system, as the processing center of the AUV, industrial computer (IC) board performs command decision mechanism to the slave computer.**

Ⅰ.INTRODUCTION

The team NACIT was founded by the Northwestern Polytechnical University Underwater Vehicle Institute and Xi'an JIAYE Aviation Technology Co. Ltd. The two partners cooperated on the overall design, propulsion, navigation control, precision machining and other aspects. We spent ten-month design and processing cycle developing an AUV which is able to achieve a variety of functions. It is the AUV that taking part in the 19th IAUVC held in San Diego in July 2016. As the world's top level of underwater vehicle competition, it puts an emphasizes on the autonomy of underwater robots, requiring the underwater robots' autonomous decision, maneuver, and using its actuators to complete tasks such as firing torpedoes, underwater acoustic positioning, retrieve objects and so on. During the race, the underwater robots can not be allowed to be remotely controlled or to connect with the shore operators.

The research and development of the AUV is a complex and systematic project with obvious multi-interdisciplinary characteristics. In the aspect of modules integrating, on the one hand, we chose the new technology in the marine market and purchase end-to-end commercial off-the-shelf modules with high reliability reasonably as far as possible, on the other hand, we also do it on our own and completed some parts' design and processing, for instance, the mechanical grabber. However, according to the demand of the competition, to compatibly integrate modules which are not related so closely requires engineering practical experience, hands-on ability and interdisciplinary collaboration. Therefore, we divide the team into three groups of machinery, electronics, and software.

Ⅱ. MECHANICAL SYSTEMS

Paxer's mechanical system consists of the vehicle frame, sealed hull, cameras, actuators and external enclosures. The vehicle measures 1150mm in length, 580mm in width and 450mm in height. Its weight is 42Kg. Through Solid Works software, the entire structure achieves paperless and visualization design, which brings us great convenience from 3D modeling to the manufacturing drawings. After completing the modeling, the entire vehicle frame was simulated based on ANSYS. We also used the software STAR-CCM+ to simulate the underwater attitude of the vehicle and the trajectory of the torpedo and marker.

Fig. 1: A Solid Works Rendering of Paxer

A. Frame

The side frame is mainly used for fixing vehicle sealed cabin, actuators, and plays an effective protection role. The side frame made by Aluminum Alloy materials was processed by laser cutting, which ensures the requirements of rapid processing and installation. The inspiration of the shape of side frame comes from Optimus Prime in the film *Transformers*. In order to present a beautiful appearance design under the premise of guaranteeing structure function, we hope "Optimus Prime" can walk from land and air to underwater to complete the missions.

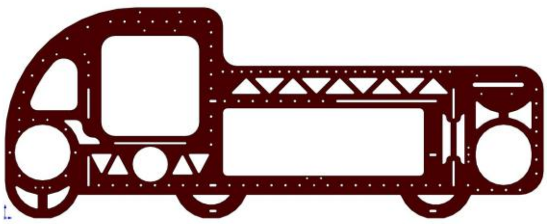

Fig. 2: Vehicle’s Side Frame

In addition to the side frame, the vehicle’s bottom bracket is the main load-carrying structure which bears the weight of the instrument module, the battery pod and the actuators. Most structures of Paxer are linked to it to prevent the side frame bearing too many loads and to guarantee the stability of the overall structure. Besides, the center of gravity of Paxer is below its floating center, which ensures the static stability of the vehicle.

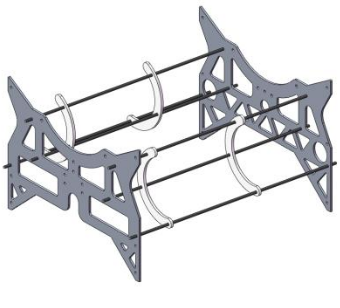

Fig. 3: A SolidWorks Rendering of Vehicle’s Main Frame

B. Hull Assembly

In order to observe the indicator lights monitoring the running status of the elements inside the cabin easily, an internal diameter 220mm organic glass was elected as Paxer’s sealed cabin. A total of 13 Subconn connectors were mounted at the end of the cabin for power supplying and signal transmission, and the depth sensor at the face can provide real-time feedback of vehicle’s depth information.

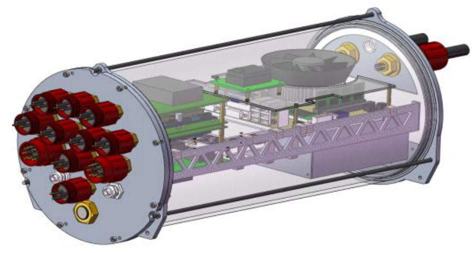

Fig. 4: A SolidWorks Rendering of Paxer’ Hull

In addition to the main pod, the seal shells of the vehicle also consist of a battery module, camera module and pneumatic device module. A mechanical pressing switch was arranged on the panel of the battery pod, which is used for emergency cut of power supply.

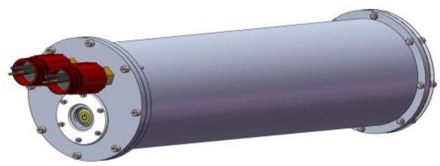

Fig. 5: Battery Pod

5 solenoid valves were installed in pneumatic unit, which were respectively used to control the torpedo launcher, marker dropper and the grabber to complete the corresponding missions. Gas cylinders are used to provide gas source for the whole pneumatic system. The pressure of the gas cylinder is generally adjusted to 0.6-0.8 MPa.

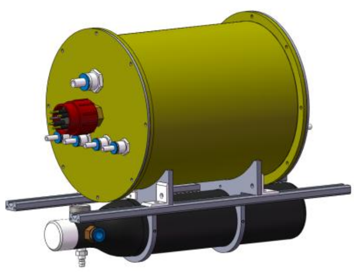

Fig. 6: Air Cylinder and Pneumatic Device for Sealing

C. Camera

Paxer’s cameras are series Allied Vision Guppy Pro F-046, for which we have designed a special waterproof sealed enclosure.

Fig. 7: Vehicle's Camera

D. Actuators

Paxer's executing mechanisms comprise two torpedo launchers, two marker droppers, a mechanical grabber, 8 propellers and so on.

a) *Torpedo Launcher*

The compressed air in the gas cylinder entered the launching tube and pushed out the torpedo through the one-way conducting valve which opened as the signal triggered. The torpedo was processed by 3D printing, of which the head is pointed while the tail has a stabilizing fin. After practical test, we find that 0.8 MPa gas pressure can drive the torpedo sailing a distance of 2 m, which can meet the requirement of the mission.

Fig. 8: Torpedo Launcher

b) *Marker Dropper*

The marker dropper adopts a double-acting gas cylinder to drive the push rod, and after the push, the golf ball in the cylinder is released.

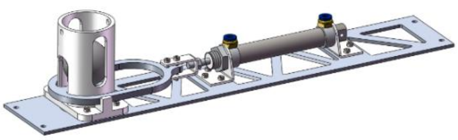

Fig. 9: Marker Dropper

c) *Grabber*

The 2016 competition missions require grabber to remove the cover and the coin stacks, so we targeted to design the manipulator which is driven by a double-acting gas cylinder. A grabber of a cross "X" type can capture over a wide range to acquire the redundancy of object grasping

Fig. 10: Active Grabber

d）*Thrusters*

The propulsion system of the vehicle consists of eight Teledyne Sea Botix BTD150 thrusters. Four vertical thrusters are used to realize the fixed depth motion, two lateral thrusters are used to achieve the lateral movement of the vehicle and the steering, and the other two to drive straight forward and backward. The vehicle can move in six degrees of freedom under the water.

Fig. 11: Thrusters

Ⅲ. ELECTRICAL SYSTEMS

The electronical system is composed of the main control switches, the main power supply, cables and various electric appliances, which provide an interactive interface for the main control computer, the sensors and peripheral devices.

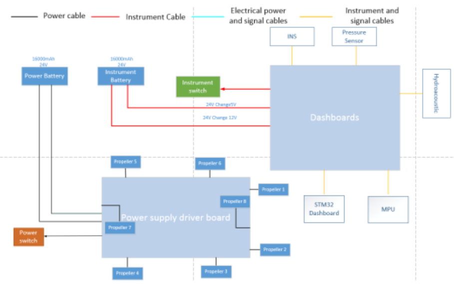

Fig. 12: Layout Schematic of Electrical System

A. Power System

Paxer's power supply shall be provided by the two pieces of 16000 mAh lithium battery. We separate driving power from instrument power supply to avoid the interference on instruments' normal function from power fluctuation caused by the start-up of the motors. Electrical instrument power supply is mainly used for the main control board, the acoustic module, the inertial navigation system, the depth sensor and the STM32, while driving power supply is mainly for eight thrusters. Voltages required in the system are 24v, 12v and 5v. According to different electrical appliances, the voltages are different, so the voltage regulator module is necessary to adjust the output voltage to achieve the normal power supply for each device. The PCB board designed based on Altium Designer is as shown in figure 13.

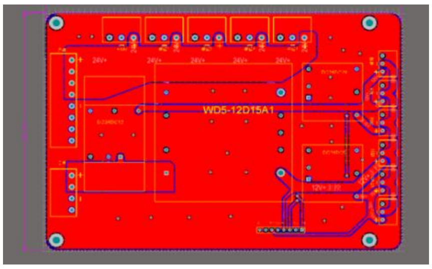

Fig. 13: Paxer's PCB Board

At the same time, we used LED lights to indicate that the working status of various power supply modules.

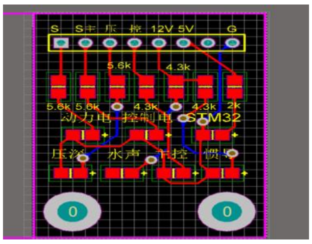

Fig. 14: Power Status Display Module

B. Computer System

The software system is powered by an Intel CPU Core Intel i7 4770K quad core processor with a motherboard KINO-DH810，including one external VGA connector, one external DVI-D connector and one internal display port connector. Expansion and I/O include one PCIe x1 slot, one mini PCIe card slot, two USB 3.0 connectors on rear panel, two USB 2.0 connectors on rear panel, four USB 2.0 connectors by pin header and two SATA 6Gb/s connectors. Serial device connectivity is provided by one internal RS-422/485 connector, three internal RS-232 connectors and two external RS-232 connectors.

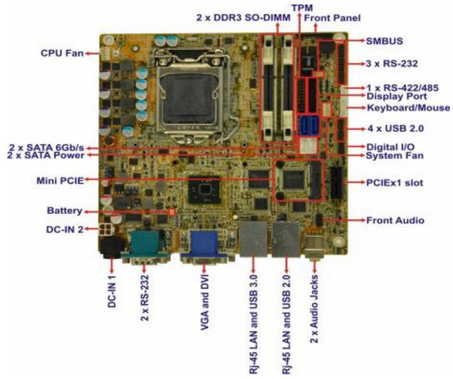

Fig. 15: Motherboard of Industrial Computer(IC)

C. Serial communication

Serial communication module builds up the communication between the industrial computer, the actuators and underwater acoustic module. IC connects with the actuators and underwater acoustic module via RS-232 serial through a single USB connection. A wide range of applicability and good noise tolerance is the reason why we choose RS232.

D. Thruster Control

In the control of the AUV, the control on the propeller is the most important which realizes AUV's maneuver in six degrees of freedom. AUV's attitude can be obtained by sensor SPARTON AHRS-8 in real time, and with the method of intelligent PID control, we can achieve precise control, so that the vehicle can remain stable under water and response rapidly while performing tasks. We designed the propeller driven board on our own, which combined with PID control method, realizing the forward and the reversal of the motors at required speed to perform direct, heave and other maneuvers.

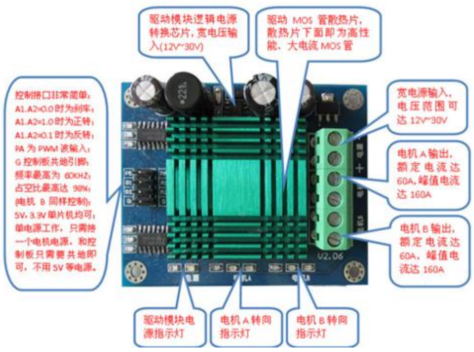

Fig. 16: Driving Board of Thrusters

As for the depth control, due to gravity and buoyancy are not completely equal, it is necessary for propellers to work continuously to provide thrust to meet vehicle's balance, to float and sink without tilt. Multi-channel acquisition control information is combined with the depth information to achieve joint control, as a result, multi input and output control mode is chosen in the depth control.

E. Actuator Control

The mechanisms are mainly driven by pneumatic device. The controller gives I/O command to drive the pneumatic valve to execute the corresponding action, making actuators, for example, grabbers, respond swiftly. After one motion, the pneumatic valves close quickly and wait for the next command.

Fig. 17: The Depth Sensor

Ⅳ. SOFTWARE

The software system of Paxer consists of two-tier structures of the host computer (HC) and slave computer (SC). The host computer is operation command center of the vehicle and responsible for dealing with the information that slave computer uploads, judging and deciding the actions, then sending instructions to the slave computer which will then reassign to the execution mechanism including thrusters, grabber and so on to accomplish the given task. During the procedure from information to the strategy, the information is defined as timing, imaging, underwater acoustic, depth and other priorities, the vehicle will carry out different tasks according to different priorities, until surface eventually.

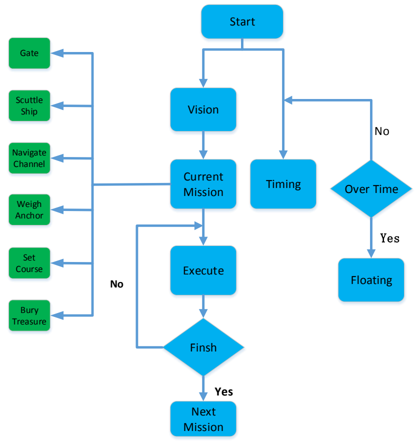

Fig. 18: Program Block Diagram

A. The Host Computer

The main functions of Paxer's HC strategy control system is to collect the data received from other systems, manage a series of analysis, and then get the instructions sent to actuators to achieve real-time data analysis and vehicle control. The strategy system has many modules, which is composed of initialization module, task switching module, communication module, image processing module, data analyzing module, data log module and human-computer interaction module.

Fig. 19: The Human-Computer Interface

B. The Slave Computer

The hardware of SC system mainly consists of the controllers, the sensors, the actuators. The master controller is of STM32F103 "enhanced" series. This chip is based on the ARM Cortex-M3 kernel that designed for embedded application with high performance, low cost and power consumption, which makes its comprehensive performance very high. The hardware resources contained in it are abundant which makes it easy to complete complex tasks and convenient to add new functions during test.

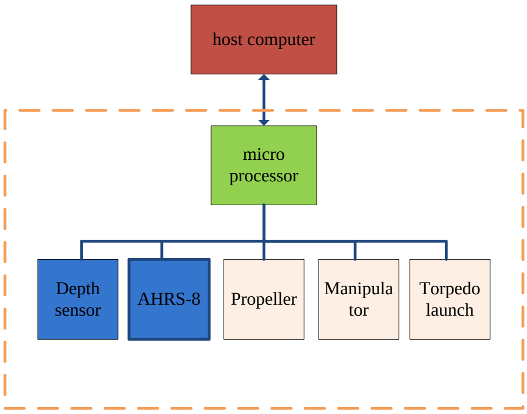

Fig. 20: The Slave Computer Frame

C. Vision

The visual system of Paxer is equipped with two guppy Pro F046-C cameras with the wide-angle lens MY125. The whole system consists of the camera module, the vision model module, the image processing and analysis module, data log module, image information feedback module.

Fig. 21: A Screen Shot of Vision Processing

Among which, the vision model module achieves the coordinate conversion from 3D coordinates in physical reality to the 2D camera image plane.

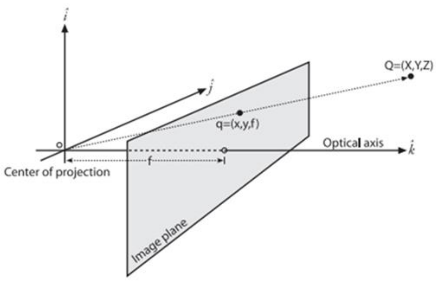

Fig. 22: Image Coordinates

D. Passive sonar

In passive sonar direction system, the objective's distance and orientation can be calculated according to the existing array parameters after direction finding. The passive ranging method is mainly composed of azimuth method and time difference method, both of which use 2 or more sub arrays with very long distances. In addition, there is also a passive ranging method which utilizes a single hydrophone to receive signal and completes warping transform. As the LOFAR (low frequency analysis record) figure in a single hydrophone implies the distance and motion information of the objective, we determine its distance with geometric algorithm through the known information.

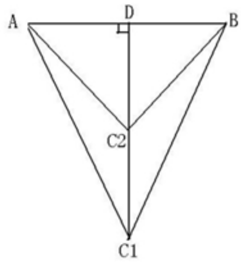

Fig. 23: Geometric Ranging Method

V. VEHICLE STATUS AND TESTING

In order to simulate the mission environment of TRANSDEC facility as far as possible, we built up 1:1 simulation experiment environment in the multi-function pool of Northwestern Polytechnical University. The water tightness test and maneuver experiment of the vehicle have been completed here. Testing is still underway to prepare for the RoboSub competition and we strive to debug Paxer to the best state.

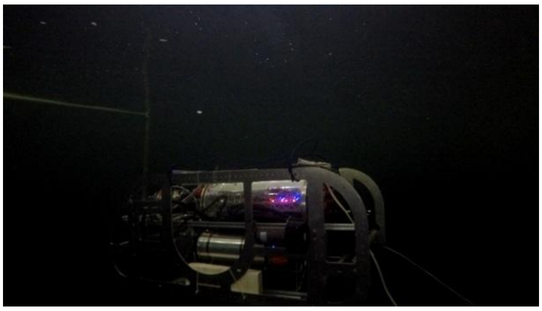

Fig. 24: A Pool Test of Paxer In Progress

ACKNOWLEDGMENT

It is the first time for NACIT to participate the RosoSub competition. We know full well that it is difficult to complete this work, but fortunately, we got a lot of support from organizations and friends all the way. NACIT thanks every friend who has given us assistance sincerely, they are Professor Pan Guang, assistant professor Huang Qiaogao, associate professor Zhang Xiaoji, all of the above mentioned teachers are from Underwater Vehicle Institute of Northwestern Polytechnical University. Their patient guidance gave us inspiration in confusion and help us find the courage to grasp hope for success. We also gained plenty of beneficial advice on mechanical processing and circuit design from engineers He Rong and Li Guang who work in the CSIC 872 factory. Mr Tong, the administrator of the multi-function pool of Northwestern Polytechnical University, helped us as much as possible while debugging the AUV. The Underwater Vehicle Institute and multi-function pool laboratory of Northwestern Polytechnical University provided convenience for our office, assembling and debugging. Xi’an Jiaye aviation technology company gave us full support in parts processing.

It is worthwhile pointing out that we would like to express special thanks to the NACIT's sponsor and chief guide faculty, Professor Pan Guang. Without the support of the Yangtze River scholars fund of whom, we can never come today. In addition, Prof. Pan also helps us solve practical difficulties encountered in the development of NACIT with his personal influence, we appreciate which sincerely.

Fig. 25: The NACIT Team With Paxer