T SOARER
TECHNICAL REPORT

MATE
MARINE ADVANCED TECHNOLOGY EDUCATION CENTER

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1 ABSTRACT

Soarer is designed specifically for underwater exploration and scientific research. This report shows the technical aspects of the ROV.

This time we adopt the frame structure, and use the aluminum alloy which meet the requirements of the solid structure and also reduce the weight of the robot, make it possible to accomplish the explore and search and rescue mission more flexible. Triangles Structure are widely used to ensure the stability of the robot structure. Furthermore, Symmetric layout strategy makes the robot is more convenient to translation and rotation. Camera section contains four cameras, a USB camera and three AV wide Angle, so as to have a comprehensive understanding of the underwater environment point of view. There are nine brushless thruster control of the robot. Use the STM32 as master, the control system is the use of C language. The data transmission system consists of CAN bus and USB bus.

This is the second time our team is participating in the MATE competition. After the experience of last year's Contest, we assigned more attention to workspace safety and flexibility.

The complicated technical tasks began with mechanical design and installation, and then hardware and software debugging followed. Besides, we took measures to optimize the process of project management. We are trying our best to build up a homely atmosphere for all of the team members.

SOARER
TECHNICAL REPORT

TOTAL OF CONTENTS

2 BUDGET REPORT

Classification	Items	Price(USD)	Price(RMB)	Donation(USD)	Donation(RMB)
Mechanical Materials	Aluminum Profile	227.75	1420		
	Circular Aluminum Ingot	210.1	1310		
	Square Aluminum Ingot	51.32	320		
	Acrylic Barrel	142.74	890		
	Acrylic Hemisphere Cover X4	192.46	1200		
	Galvanized Screw	19.25	120		
	M6 \ M5 Nut	11.87	74		
	M6 \ M5 Inner Hexagon Screw	14.27	89		
	135°Corner Pieces X100	73.78	460		
Modeling Material	45°Corner Pieces X100	51.32	320		
	ABS Plastic Board x10	85	530		
	Lime	32.08	200		
Control box materials	Waterproof Engineering Plastic Box	125.1	780		
	Asus B75 Mainboard	51.32	320		
	Pentium G2030 CPU	71.85	448		
	Kingston Memory Chip	28.71	179		
	Seagate	52.77	329		
	Wide Power Supply	39.94	249		
	PHILIPS Display	112.11	699		
	Mofii	7.86	49		
	TP-LINK	6.26	39		
	TianMin Acquisition Card	55.33	345		
	Air Plug	136.49	851		
	Switch and other parts	68.89	429.5		
Robot Material	Connie Brushless Motor X10	0	0	2405.77	15000
	Anonymous Flight Controller X2	125.74	784		
	Arduino MEGA 2560 X2	25.66	160		
	USB Wide Angle camera X2	68.97	430		
	AV monitoring Night-vision Camera X6	187.65	1170		
	Deep Water Connector X8	240.58	1500		
	Four and a half Leaf Blade X10	157.18	980		
Electronic Materials	Electronic Governor material X15	240.58	1500		
	Main Control Board Material X4	64.15	400		
Chemical Materials	Epoxy Resin X8	279.39	1742		
Sensors	Liquid Level Transmitter	91.42	570		
	Conductivity Test Pen	44.91	280		
Utility Class	Electronic Tools	115.48	720		
	Machine Tools	107.46	670		
Processing Fee	PCB Production	513.23	3200		
	Laser Cutting	561.35	3500		
	TOTAL COST OF SOARER	4692.3	29256.5	2405.77	15000

NOTE:
1) Exchange Rate: USD:RMB,100:623.5
2) Coney Brushless Motors are donated by Coney Company.

3 SAFETY MEASURES

3.1 ELECTRICAL SAFETY

In order to protect the main chip, a fuse was installed in the main circuit to prevent the large short-circuit current burning out the chip. In addition, the widely distribution of the diodes in the circuit is an effectively way to prevent some mistakes caused by the reverse connection. Extraordinarily, on the communication chip, TVS is settled as a bodyguard, which is a kind of diode used to protect a precision circuit with any amount of advantages such as higher response speed, larger transient power and lower leakage current in breakdown voltage deviation. All of these sides can effectively protect the chip.

Legend: Fuse

3.2 MECHANICAL SAFETY

The handmade protective screenings around the motors can greatly reduce the potential harm caused by the contact between our hands and the propellers. Any sharp angles have been polished when we were processing each parts in order to protect us. Safety marks have also been placed on all the places necessary to remind every user to keep away from danger.

**Legend: Waterproof Camera**

3.3 WATER TEST SAFETY

Every time before launching the experiment under water, for the sake of the safety of the robot, we use a multimeter to confirm whether every circuit connection is correct carefully. Especially, we set up an experiment to check the water tightness of the circuit cabin. The cabin is fixed with ballast and can stay at the bottom of the pool for more than 24 hours to ensure the water tightness of it.

4 DESIGN RATIONALE

4.1 MECHANICAL STRUCTURE
4.1.1 THE MAIN STRUCTURE

circuit module — framework — manipulator — thrusters
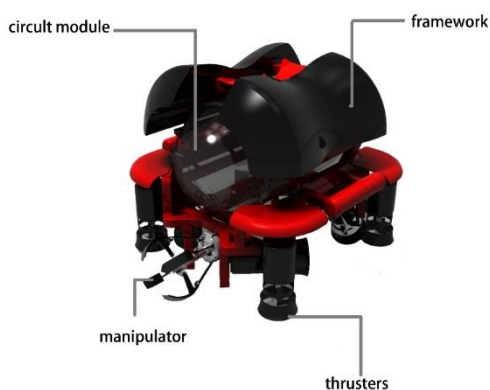
This time, the revolutionary change of the ROV is mainly the shift of the robot's major structure from the plate to the 420mm*420mm*380mm framework, which dramatically reduces the weight of the main body of our robot, as well as improves its appearance；the shift of the robot's original circuit from outside to the middle of aluminum profile painted a layer of paint, which beautifies the mechanical structure. Compared the framework structure with the plate structure, the frame structure with reduced facing water area can reduce the resistance of water and the load of motor more effectively, so it is convenient to adjust the posture.

The circuit bucket is made of 10mm-thick-acrylic bucket. We take the water pressure into consideration and choose drum structure. The robot can bear greater water pressure because rotundity can resolve pressure. The front end is a semicircular cover, which can provide the cameras with larger vision. The back end is a metal round cover, which helps to meet the requirement of circuit bucket i.e. bearing hydraulic pressure. The interference fit between metal end cap and bucket achieves waterproof requirements. The water resistance is reduced effectively by the streamlined buoys on the top of the robot.

4.1.2 THRUSTERS LAYOUT

Eight thrusters are installed in the robot in total, of which four thrusters are installed in the vertical direction to control the rise and dive of the robot. When the thruster moves in the positive direction, the robot moves upward; On the contrary the robot moves down. The other four thrusters are installed horizontally on the bottom of the frame of the robot to control the robot to turn forward, backward, left, right and spin. When the NO.1 and NO.2 thrusters rotate, the robot goes forwards; when NO.3 and NO.4 thrusters rotate, the robot backwards; when NO.1 and NO.4 thrusters rotates, the robot turns right; when NO.2 and NO.3 thrusters rotate, the robot turns left; when NO.1 and NO.3 thrusters rotate, the robot rotates clockwise; and when NO.2 and NO.4 thrusters rotate, the robot rotates counterclockwise.
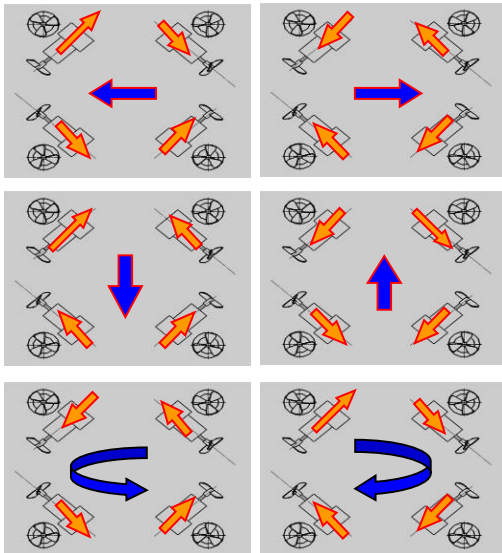
Legend：Thruster

4.1.3 THE GRAVITY CONFIGURATION

The heavier components like thrusters are mounted on the bottom of the robot, and lighter components like circuit bucket and buoys are mounted on the top of the robot, which form the structure of gravity downward. This structure is similar to the tumbler. Even if the robot suffers greater water resistance, it can maintain stability. The framework of the robot and the layout of thrusters are symmetrical, so it can provide basic guarantee to realize posture balance algorithm.

4.1.4 AGAR SUCKER

Agar Sucker

The device used for sucking the agar is made from a metal sheet material, which has a spine-like lower end. They are arranged in a circle, bottom inwardly folded to form barbs, like an inverted cone. Barb's angle is decided by efficiency while the agar was sucked at 10°,15° and 30° .The diameters of lower and upper holes are 50mm and 100mm, respectively. This specification is based on the capacity of the agar. Considering the large pressure of a depth of 10 m underwater, the material hardness must meet the deformation requirement, so we decided to use metal material. A half naked ball connected the main body of the robot by a spring, which can be easily and quickly removed and installed, as well as avoid the disassembly trouble when it fixed with screws and nuts.
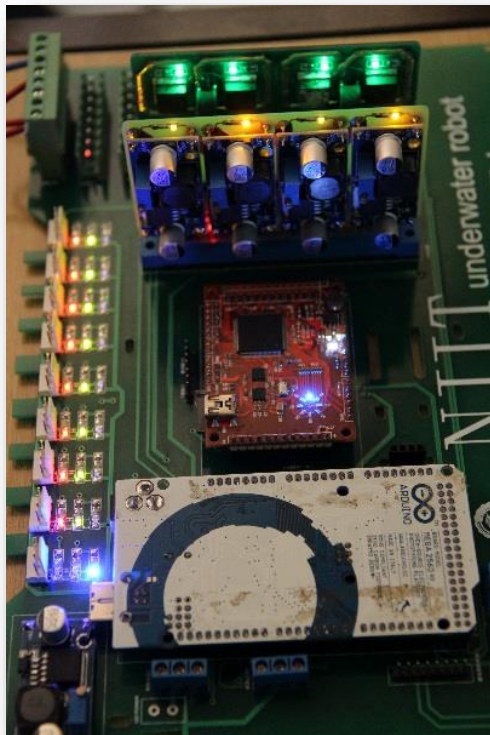
4.1.5 MANIPULATOR

Our manipulator is designed as four claws. Because of the four claws, it can carry out multidimensional tasks to meet the requirements in the competition.

4.2 CIRCUITS DESIGN
4.2.1 MAIN CONTROL BOARD DESIGN

We choose dual core mode as our control mode. That is to say, ANO_TC high integration flight control board and ARDUINO MEGA2560 development board are the main controller and the coprocessor for the robot soarer. The main controller takes the low-powered micro-controller chip STM32F407 (Coterx-M4 kernel), which works at the frequency of 168MHz, as the core unit. The main control board is a 4-layered board, i.e. signal layer, GND layer, VCC layer and signal layer. On the main control board, there is a 9-axised attitude sensor, 20 PWM output ports, 2 USART ports, 1 CAN bus, and 1 SWD download port. The main control board is connected to a 2-larered adapter board. The coprocessor's core chip is ATmega2560, in which the ARDUINO's rapid development tool BOOTLOADER is integrated .Coprocessor and main controller are put on the main control switch board side by side. The main control switch board integrates DC - DC module and BTS7960 driver module and provides 10 control signals to the electronic governor. Multi-channel DC - DC module is responsible for multiple voltage regulator, providing voltages with strength 12 v, 9 v, and 5 v respectively.

4.2.2 ELECTRONIC GOVERNOR

Because we change the motor of the system from the brushed DC motor into a brushless DC motor, the driver is replaced to some extent, and the homemade electronic governor is applied. Electronic governor is made of hardware and software. Software takes STM8 as the core. Due to that the precision timer acts as the core, the motor operating current and external supply voltage can be constantly monitored. At the same time, external PWM signals input can be captured, and be converted to three-phase control PPM signals, and the working state of MOSFET pipe can be detected to ensure that the system is in a stable security situation, if there is an accident, the motor can be stopped work in time, which maximally protects the system. Refer to hardware, it is composed of battery voltage monitoring circuit, commutation control circuit, current detection circuit, and the zero crossing detection circuit of the electric potential, which can obtain the comprehensive working performance of the motor, and also provide sufficient and reliable working performance.
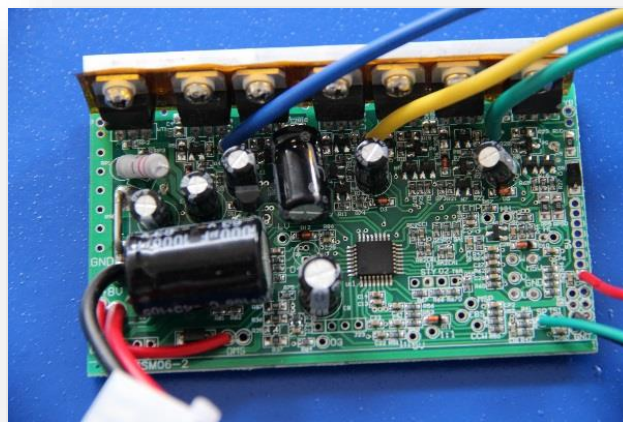
4.2.3 SENSOR DESIGN

The system uses a multi-sensor-scheme. The sensors can be divided into two aspects, one kind is used to acquire attitude, and the other is applied in manipulator. Three main sensors are used to acquire attitude. We used MPU6050 which is the fusion of an accelerometer and gyroscope, electronic compass AK8975 and HL-89 liquid level transmitter.

MPU6050 is used to acquire the three axis acceleration and angle velocity variation, resolve four elements of attitude algorithm and transform the Euler angle; AK8975 is used to get the angle of drift, inertia compensation movement; HL-89 liquid level transmitter is used to measure depth. Sensors in manipulator are a micro switch and a metal sensor, mainly used for preventing manipulator overload.

4.2.4 DESIGN OF ELECTRICAL CONNECTION

In the MATE competition of last year, our team suffered a great failure in the electrical connection. The electrical connections we used last year were almost un-replaceable, difficult to repair and also unreliable. For example, the connection between the electric circuit and its outside was a waterproof connector, which caused a big difficulty on repairing. Because we had to open the connector completely when some components were broken. If there was a failure with the motor, replacing the motor would be a huge project.

In the design of this year, we adopted the deep-water connectors and the aerospace connectors, both of which were highly reliable, easy to disassemble electrical connection devices, especially the deepwater connector whose multilayer waterproof structure ensured the water tightness between the connectors and circuit. The aerospace connector on the control box was a kind of highly reliable electrical connection device. We made a detailed anti-reverse protection to ensure the comprehensiveness of the entire system.


The main improvement for the inside electrical connection of the circuit warehouse was controller connection. Last year, because of lacking of consideration, we adopt the method of putting the control plate in the connecting adapter plate directly, which was unreliable in long distance transport. The main controller dropped from the motherboard when it was brought to the competition field due to the vibration. This year we have adopted a mechanically fixed manner, and set aside fixing holes on the controller. The control panel was fixed on the floor by studs and screws, which avoids the possibility of loosening.
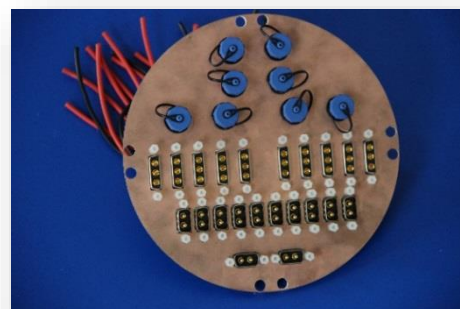
4.3   SOFTWARE SYSTEM
4.3.1 MAIN CONTROL PROGRAM
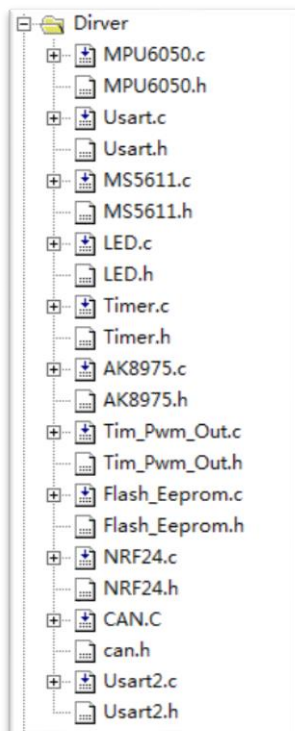
The main control program consists of two main parts of driver. One part is the underlying control driver of ANO flight control board, and the other part is the underlying driver of ARDUINO 2560.

The underlying control driver of ANO flight board is mainly composed of four parts, that is, system configuration files, IIC bus driver files, module driver files and the user control file. System configuration files contain the chip startup items provided by ST Company as well as open source-the standard library function ST-F4. IIC bus driver files are fast IIC non open source driver files provided by ANO_TC Company. Module driver file contains the LED accelerator test lamp, data transmission of serial port, serial port communication coprocessor, controlled CAN bus, the timer module, PWM generation timer module, MPU6050 IIC AK8975 IIC communication, MS5611 communication, IIC communication, NRF24L01 communication SPI, FLASH storage and read and several functional modules. They are packaged into the function interface mode to ensure the independence of each module and make it easier to be cited by the upper algorithm. The user control file contains the main function, interrupt service function, configuration files, attitude calculation, the control file, controlled data file and data transferring file.
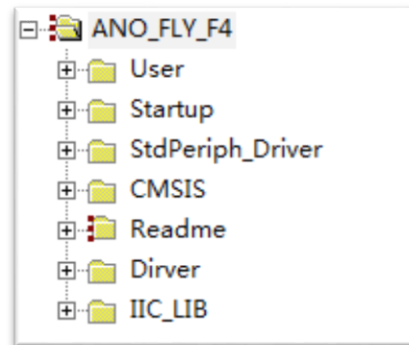
ARDUINO acts as a rapid development platform. That is to say, the bottom configuration is included in its development environment, and what we need to do is to initialize configuration on the interface and complete the initialization of serial port, the data port, AD port and the stepper motor output port in setup function.

4.3.2 COMMUNICATION PROTOCOL

Communication protocol is mainly divided into three parts, which are the CAN bus communication between the control box and ANO_TC flight control, the backing data between ANO_TC flight control and upper computer and the data exchange between ANO_TC flight control system and the ARDUINO coprocessor. The main reason of adopting the CAN bus communication is to keep the real-time performance of the ROV movement. The CAN bus as the industrial control field bus, it is famous for its high transmission quality and the real time on-site control capability. Control box complete the sample of handle every two hundred milliseconds and sends the data to the communication bus. ANO_TC flight control receives the intruction of the bus control in the form of the highest priority interrupt and decodes the data every two milliseconds, then realize the real time control of the ROV. We adopt USB-TTL to realize backing the data between ANO_TC flight control and upper computer. The backing data needed to display are as follows, which are the acceleration, the angular velocity and the declination of the ROV in the xyz axis, the PWM duty cycle received from the 12 motors, the control signal received from the CAN bus, Euler Angle and Yaw Angle. It is needed more than 2.375 KB of data volume to fully describe the data though our calculation, combined with frame, type, CRC check digit. The data volume in total is 2.57KB, which is 21056B. Adopting flight control serial port under the 115200 baud rate can make completing transmitting these data in 200 millisecond come true, which ensures the reliability of the upper computer data, and shall not affect the control signal. We adopt the serial port to realize the data exchange between ANO_TC and ANDRUINO. The serial port as a short distance of real-time control, the direct electrical connection of communication of TTL level is more reliable.
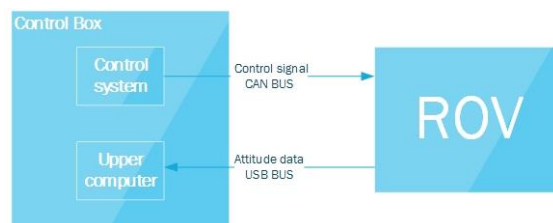
4.3.3 BALANCING ALGORITHM

Balancing the posture is very important to complete the task smoothly, so we must adopt certain balancing algorithm. Firstly, we model the ROV with mathematical method. There are many mathematical tools to describe the attitude of the ROV, such as Euler Angles and Quaternion. By analyzing the model of the ROV, we find that the speeds of the motors on the four feet of the ROV are input parameters and three Euler Angles are state variables. This is a typical nonlinear and strong coupling system, which has multiple inputs and outputs (MIMO).We use the MPU6050 gyroscope to measure the attitude of robot. We combined Euler angle with sensors, because the quaternion can be easily measured with sensors and Euler angle is convenient to apply in algorithm to control. It is easy to control the robot when we firstly measured quaternion with sensors, then the quaternions were transferred into Euler angle with formula. Because the actual angle of the ROV itself won't have too big change, for the sake of simplicity, it can be seen as a linear system. On the premise of a linear system, we adopt digital position-type PID algorithm. The control algorithm does not need a precise model. In addition, when the parameters have been adjusted properly, satisfactory control effect can also be achieved.

4.3.4 IMAGE PROCESSING

4.3.4.1 MEASURING THE DIMENSION OF THE SHIPWRECK
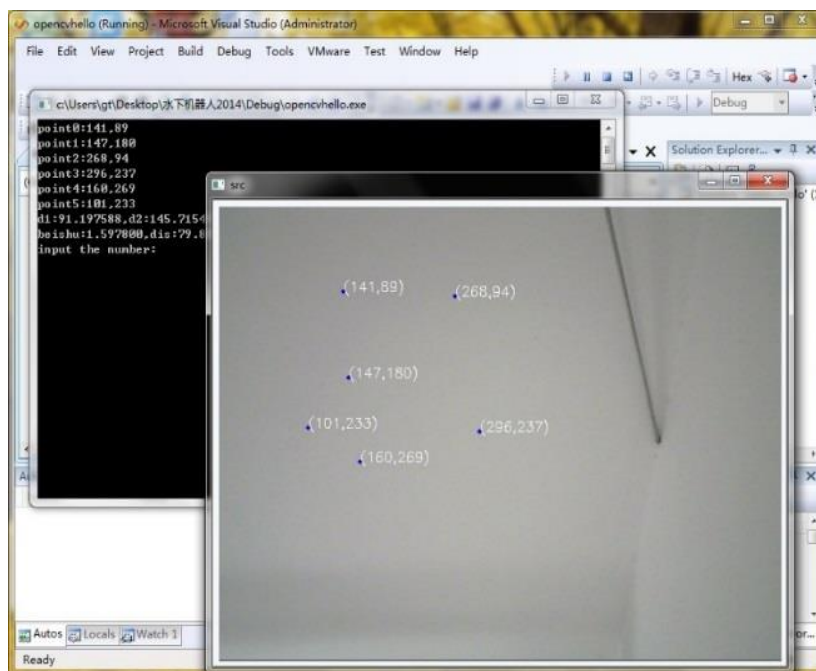
Legend:

The interface which is used to measure the boat through proportion calculation.

We adopt ratio method to measure the length, the width and the height of the wreck. First, the ROV put a framework on the shipwreck, then take a photo including the whole framework and the shipwreck. Second, the field of OpenCV is used for image processing. We use the mouse to click on the image of the framework and the shipwreck for getting the coordinates of these points, then relative length of the framework and the shipwreck can be calculated and finally we can get the ratio. The actual dimension of the shipwreck can be got by the ratio multiplying by the length of the framework.

4.3.4.2 PHOTOMOSAIC

In the first place, we takes five photos. The processing of photomosaic comes down to extracting of the feature points, matching of detected points and fusing of image, etc. Stitcher provided by OpenCV can easily make photomosaic come true and it works well.

4.3.4.3 UPPER COMPUTER

Upper computer software is written by MFC, and the main function of this part is to display the data frame from USB serial port.
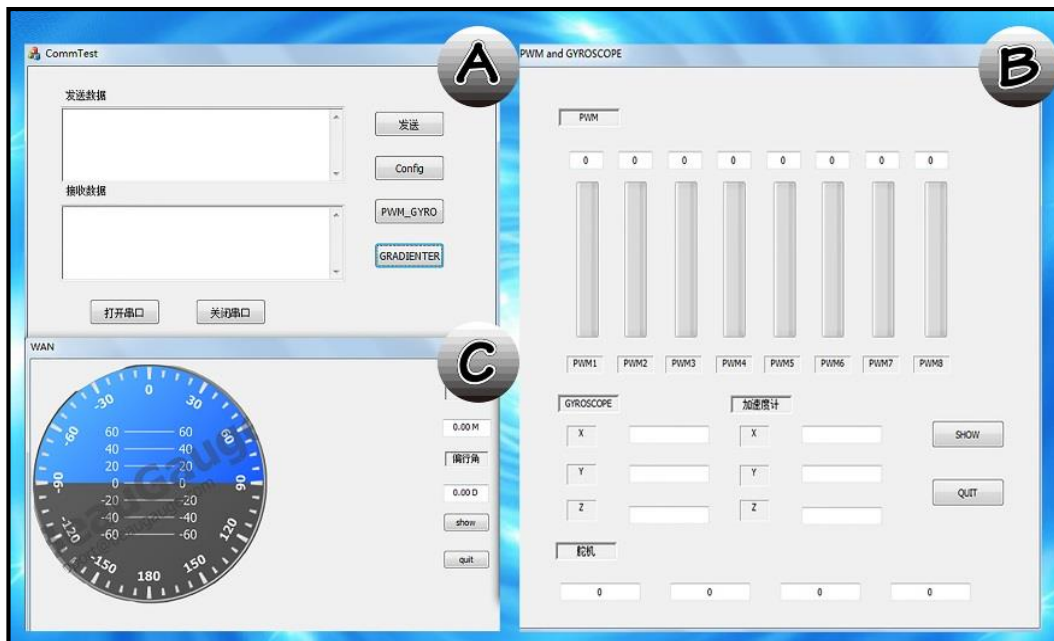
Legend:

A. The main interface of the whole project, as well as the basic component of serial communication.

B. The interface which gives the real-time data of PWM, gyroscope, acceleration and the steering gear.

C.The interface showing the balance condition of the ROV.

4.3.4.4 CONTROL END DESIGN

The X86 platform and embedded micro controller are adopted to build the control end. We transform the professional instruments toolbox to a multifunctional control box. The control box has a built-in X86 platform and runs the WINDOW operating system with built-in upper computer and figure treatments programs. It's very convenient to observe and operate the ROV at the same time. The transmission center of controller is Alientek STM32F103 development board, and the main function of this part is to take sample from the operating handle. The control box also contains a voltage current data-showing meter to monitor the current of ROV in real-time. There are a 40A fuse inside the control box and two switches on the control box, which can be used for over-current protection and emergency stop operation.


Legend:The control box.

5 CHALLENGES AND TROUBLESHOOTING

5.1 TECHNICAL DIFFICULTIES

In the process of ROV production this year, we confronted with some mainly technical difficulties. One is the contradiction between the strength of mechanical structure and fluid resistance. One is lacking of a suitable power source. One is the superior difficulty of overhaul and the other is the communication system.

Among our three generations of robots, the first and second generations focused main on stable structure, choosing the board structure. But the structure formed a great resistance surface, sacrificing majority of the kinematic velocity. The third generation used the frame structure of PVC pipe in the pursuit of kinematic velocity. While the structure greatly reduced the fluid resistance, but the robot itself can't keep stable, being prone to rollover. Therefore, in the production process of the fourth generation robot, we adopt the framework structure of aluminum profile, to adjust the overall center of gravity of the robot, ensuring both the stability and low fluid resistance.
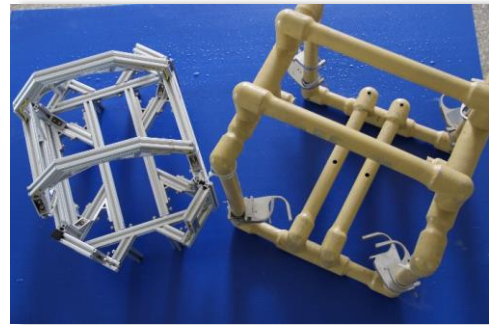
The power source is a sever problem which has troubling us for long time. In the development process of the first two generations of robots, we use the large pump as the power source. The pump caused bad exertion for its heavy weight, low energy efficiency, and single veer. In the development process of the third generation of robot, we use the small water pump with high efficiency and large power. Although it met the technical requirements, but the power of paddle and power source do not match, resulting in the overload of power source or low energy efficiency. Therefore, in the production process of the fourth generation of robot, we eventually got sponsorship from Kangni Company after researching varieties of thrusters of many companies and communication with enterprises. They provides us with Brushless DC Motors which have high energy efficiency, large power and high speed. At the same time, we copied the fairing, chose the moderate semi-submerged propeller and basically solved the long-standing problem of our power source.

Furthermore, the faults and maintenance of electrical aspect are always the main problems consumed majority of time. The main reasons for this phenomenon has two aspects, one is the electrical design layout is not reasonable, the other is the electrical connection is not reasonable. The former point is apparent in the first and second generations of robots. The circuit being bundled into the opaque circuit warehouse circuit will be bundled into an opaque caused problems to know the situation inside and detect the problem. We have improved greatly in the three generation of robot. Each module realized layout specification, and transformed all module into the rapid extraction to facilitate the replacement. At the same time, we added plenty of indicator lights and transformed the opaque metal of the circuit warehouse into a transparent acrylic cabin. The improvements can meet the requirement of knowing working conditions of the circuit without opening the cabin. When it comes to the aspect of electrical connection, the first and second generations of robots are not completely removable. Once external firmware damaged, the replacement is very troublesome. In the three generation, the design of a deep-water connector was added which can ensure that the circuit module can be disassembled. The external component are connected to suitable air connector which ensures the rapid replacement.

Finally, there is always a problem for us is the communication between control end and robot end. We firstly used 485 communication schemes, can be applied to control the robot. But the phenomenon of a large number of dropped frames and the delay is still exist. In order to ensure the operators can control robot better, we used the CAN bus, make the data remain in the transmission frequency of 200Hkz and choose appropriate communication cables. So we can ensure the robot update in the millisecond level to update the condition of the robot itself.

5.2   NON-TECHNICAL DIFFICULTY

Beside the technical difficulties described above, we were faced with many untechnical difficulties in the process of production. There were three main problems, which are time limit, debugging venue and technician's ability.

Due to a variety of other factors such as school system, we had only two months to develop a robot. Our own studies and other projects we undertook had to be taken into account in the process, so time was limit. In order to overcome the difficulty, most of our team members spent their leisure time and legal holiday time to work it out.

Legend：Debugging field

Finding debugging venue was a great problem for us. We had to buy a simple domestic swimming pool as our debugging venue for there was no swimming pool in our school. Limit depth led to the result that we couldn't simulate the competition environment better, so we had to simulate the situation of the competition in our mind, performed a variety of experimental simulation and planned the items needed to debug in the competition venue well. However, those solution could not settle the difficulties caused by venue completely.

One of the biggest problem is that we were short of talents. Our team member's majors were concentrated, which were the Machinery Manufacturing, Flushbonading and Automation, etc. The lack of the talents specializing in oceanography and Hydrodynamics led to the result that we had to rely on our own non-professional trial and experiment in the process .As far as we are concerned, we ought to trying finding more talents we need in the process of recruiting.

6 LESSONS LEARNT

Most of our team members had never experienced the process of designing ROV before. In the past, we made a small intelligent car or an aircraft in groups of two or three. The project amount was little in general, which we did not need to worry about the division and management of a team. When it comes to the design of the ROV, we started to realize that coordination and distribution of responsibilities and the management ability needed as a leader were significant to manage a team.

Compared to the project we finished before, to make an superior ROV, we could not only consider perfecting the performance of the ROV, but adding more design concept, engineering thoughts, comprehensive consideration of the design of the ROV.

Legend: We are testing the soarer

7 FUTURE IMPROVEMENTS

7.1 MECHANICAL STRUCTURE

In the future, we will use modularized mechanical structure design. The whole structure can be divided into two parts, the first is the main structure surround the circuit barrel, and the streamlined shell exterior to the major structure so as to reduce water resistance. The second is the support bracket connect to the main structure, the propeller is installed on the support bracket. The two section can be disassembled, in this way, facilitate installation and manufacture, the modular production make it strong versatility.

7.2 MANIPULATOR

In order to accomplish complex tasks, a multiple degree of freedom manipulator is quite necessary. Firstly, to have a mechanical arm of multi - degree of freedom can make manipulator reach any point within the space. Secondly, it also need a manipulator of multi-degree of freedom to fulfill the grasp and rotation. Certainly, for the sake of precise control and to prevent the wrong movement, we must select the position servo system with high precision, it can also add angle sensor, closed-loop control of the servo motor turning angle, fulfill the close-cycle control towards the angle the servo motor turn .

7.3 CIRCUIT SELF-CHECKING

In the following manufacture, we will add detection to various parts of the voltage, current and temperature. Take this as a separate system, operational data will be sent back to the operating side in real time, which can make us have more comprehensive and manifest understanding of the robot's entire state, in addition, through the analysis of the fluctuation of wave, we can find out the fault circuit will make the examine and repair more efficient.

7.4 THE PRECISE NAVIGATION

GPS signals cannot be received when robot is underwater, so do not adopt the GPS navigation. We use inertial navigation to solve this problem. With the existing gyroscope, accelerometer and digital compass, using the initial position of the robot as the origin of the coordinate system, when the robot move under water, accelerometer, gyroscope and electronic compass can measure the speed and angular velocity, and use integral to apply on velocity and angular velocity, make out the position and orientation of the robot now. Upper computer establish the initial robot coordinate system, return the result of the current position and direction parameter of the robot which is calculated by algorithm, at the same time, show on coordinate system of the upper computer. It can draw the motion trace of the robot, and eventually achieve the purpose of precise navigation.

7.5 THE HUMAN-COMPUTER INTERACTION

In the future, we will simplify operation mode of the robot to ease the burden of the operator, take more consideration of human engineering, make a more perfect scheme to the layout of the camera. offer the operator a more intuitive understand of the robot's movement , minimize the workload and achieve the most efficient operation.

8 REFERENCE

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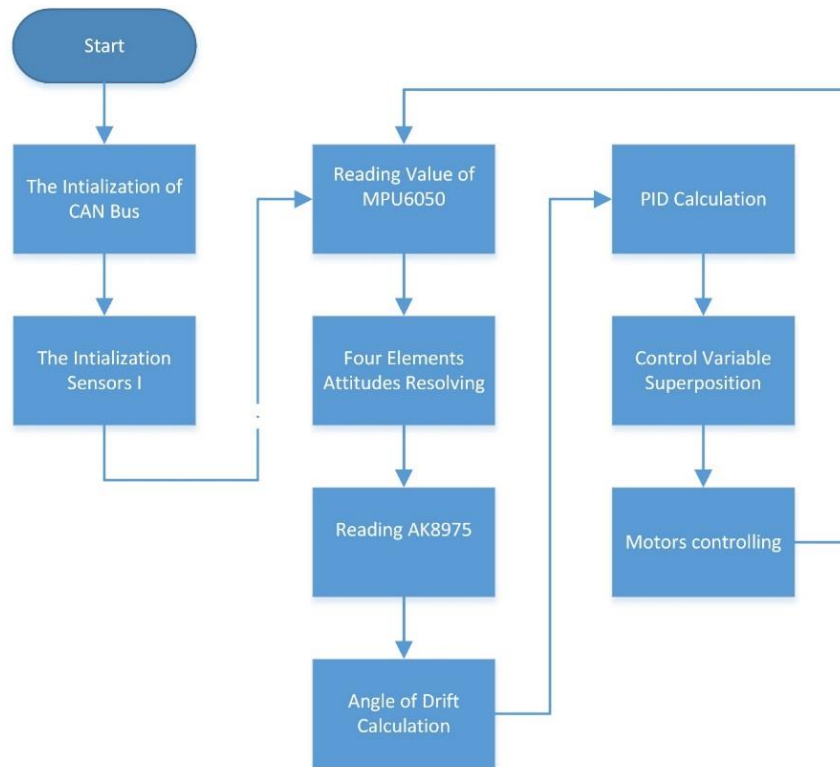
9 ACKNOWLEDGEMENTS

10 APPENDICES

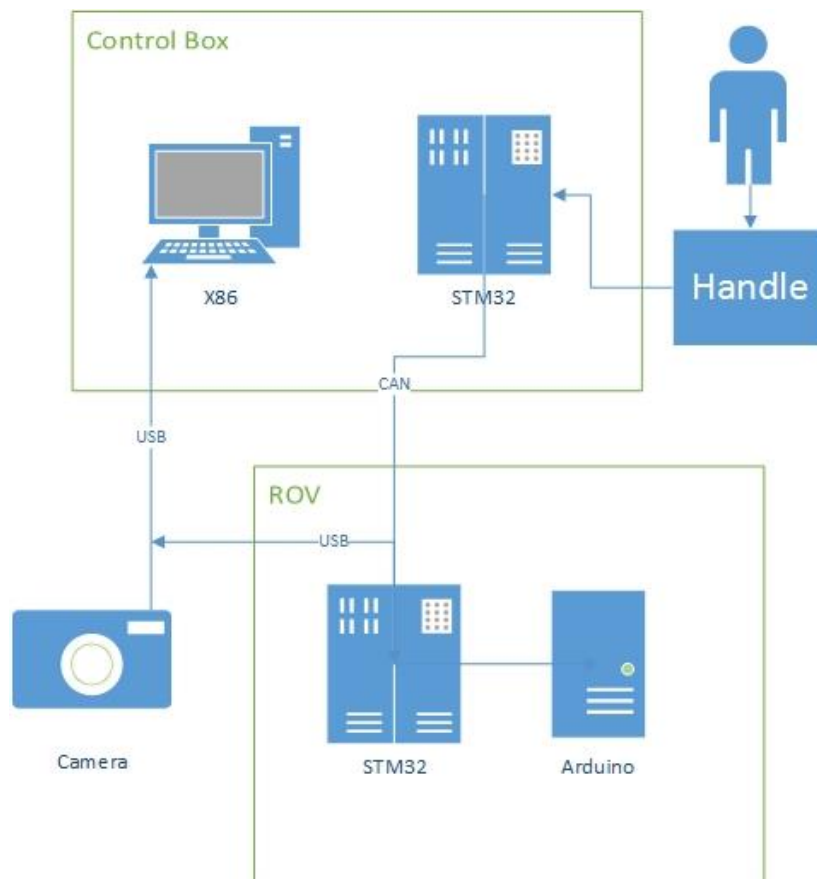## 10.1 HARDWARE BLOCK DIAGRAM
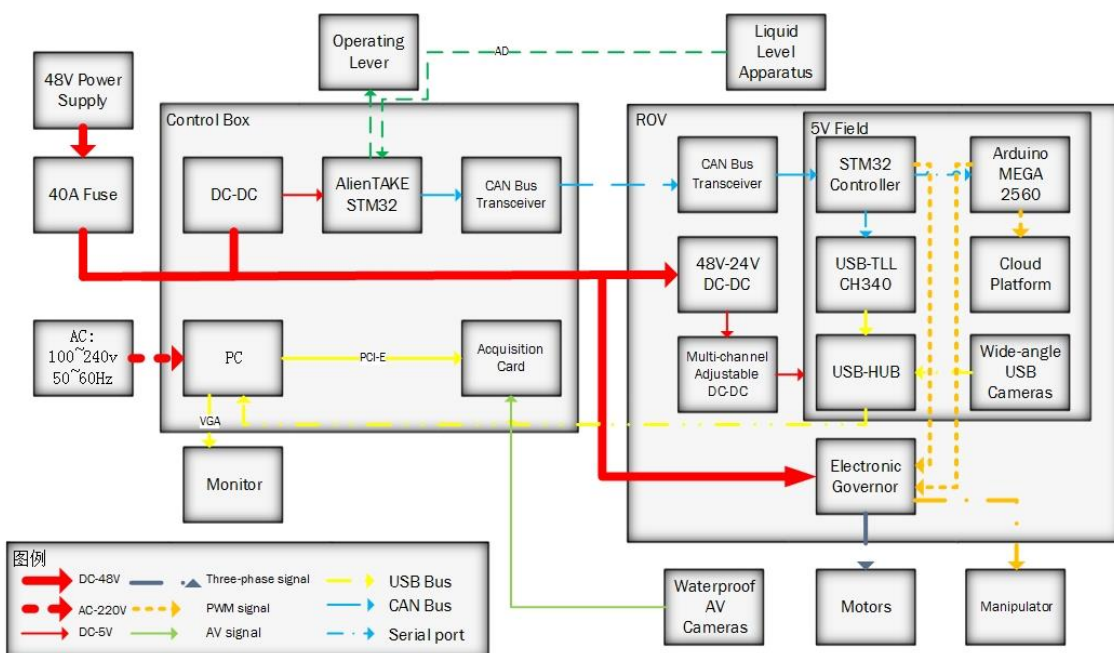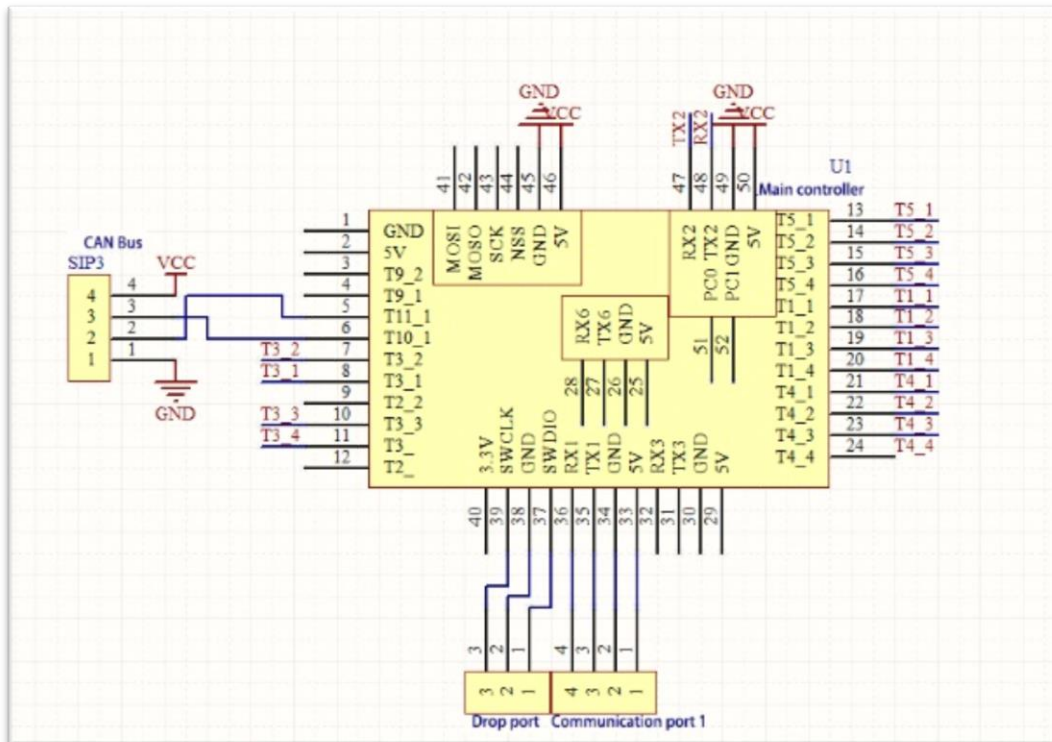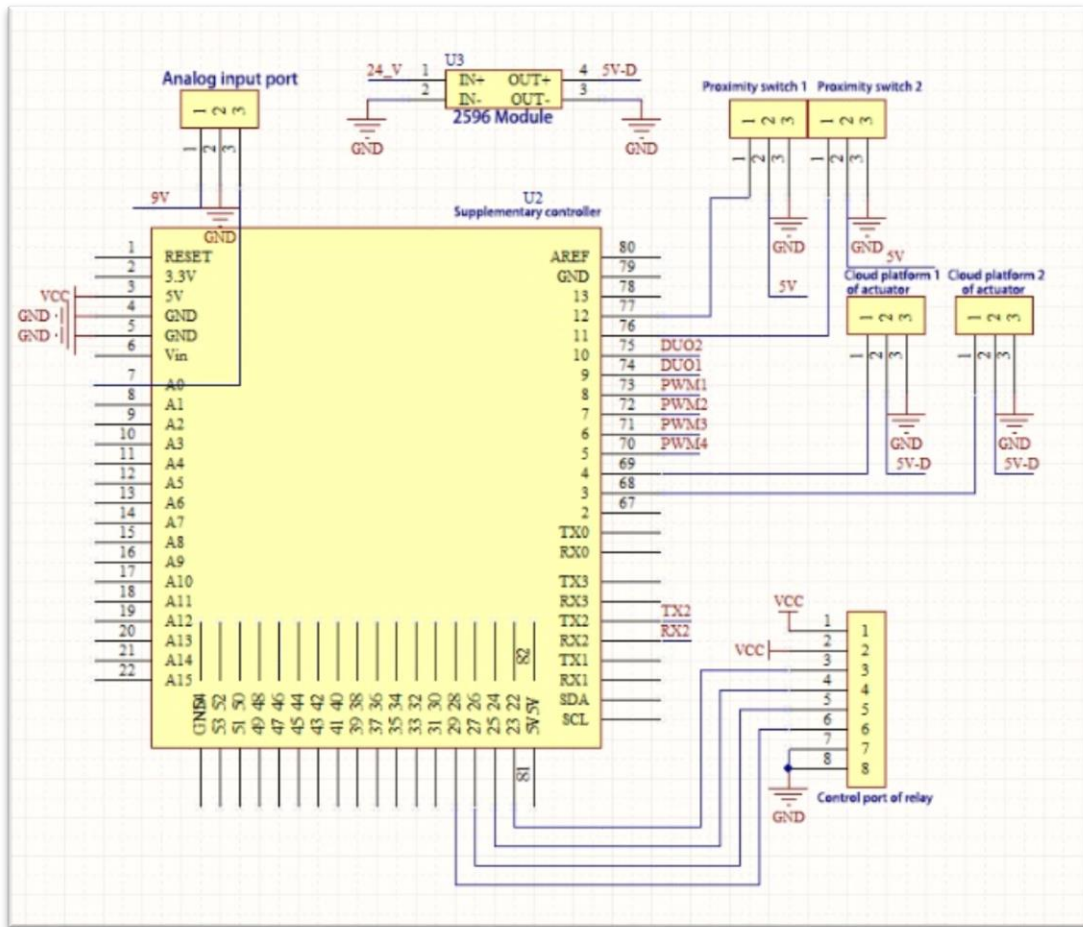
10.2 SOFTWARE LAYOUT

10.3 SYSTEM INTERCONNECTION DIAGRAM

10.4 MAIN SWITCH BOARD

10.5 ELECTRONIC GOVERNOR DRAWING