Development of a bionic fish remotely operated vehicle

Bingyu Zhu[1, *], Shuting Shao[2, a], Jiayin Yuan[3, b], Ziming Chu[4, c]

[1]Beijing Forestry University, Beijing, China

[2]Zhejiang University, Hangzhou, Zhejiang, China

[3]American Heritage Boca Camps, FL, USA

[4]Shandong University of Technology, Zibo, Shandong, China

[a]Shuting.19@intl.zju.edu.cn, [b]1063307861@qq.com, [c]1290278111@qq.com

*Corresponding author: a200323@outlook.com

These authors contributed equally to this work

Abstract

The bionic fish remotely operated vehicle is an underwater observation type of robot, which is a new idea to solve problem of strong noise and high resistance that ordinary underwater ROV cannot efficiently deal with. Due to the complex observation tasks under water, it is difficult to rely on the ordinary ROV to move noise-free and smoothly. This device is specifically designated to use for the complex infrastructure inspection and shoal monitoring. The design includes hydraulic device and propeller thruster combination to empower robot with the function of steering in three degrees of freedom, and underwater camera and sensors are established to be able to achieve digital information exchange, which allows both ground station to send control directive and receive graphic footage and sensoring data.

Keywords

ROV, bionic robot, underwater.

1. Introduction

Recently, there are various kinds of ROV (remote operated vehicles) utilized in diverse fields. Those ROVs are replacing human operators to finish 3D (Dirty, Dangerous and Dull) tasks. Human have limitations to work under water, such as the air that the divider can only use for a little amount of time and the deeper human dive the bigger pressure will get on their body. Therefore, the ROV can be used for tasks like observing under water, taking samples of water in the trench, and doing maintenance of some underwater devices. For example, lobster bionic underwater robots created years before, which are powered by mechanical feet, can only travel at a low speed, and stay on the ocean floor, and use to finish tasks in high current environments [6]. In order to get some water sample and seafloor samples in that area [lobster]. Also, there is a kind of Amphibious Robot that have a smart design-made its wheels also its propeller can both work fish- like underwater and it has big wheels which can let it move on both fleet and rocky beaches.

The core design idea of ROV is highly flexible. ROV would be equipped with power mode and silent mode, to satisfy different expectations of tasks. In some tasks about marine life observation and monitoring, the ROV would use silent mode. Moving at a relatively low speed, by only using the hydraulic press and connecting mechanism at each joint would be utilized to drive the corresponding

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joint. In this mode, the ROV would make less interruptions to the surrounding environment. The power mode uses two thrusters mounted under the pectoral fin to create enough power that allows the ROV to change position within a short period. The new design of the ROV allows both moving with a fast speed and sneak with low noise.

The outermost layer of ROV is going to be fish skin like. Silicone material is used to make protective cover. Which makes the outward appearance of ROV more like that of fish.

Except for the outside look, ROV will simulate fish's moving characteristics.

2. Structure Description

The overall mechanical mechanism of ROV is designed according to the sub-system module design method and the independent functions according to the functions to be realized. The body of the bionic robot is divided into four parts: head, bell, tail and joint.

• The head is composed of a head body and an image system. The head body includes thrusters power drive system and a side fin mechanical system for controlling pitch steering; The image system includes light system and camera system.

• Belly is composed of belly body. The top of belly body is provided with shark fin to control balance. ROV control system, communication system and sensor system are installed inside. Its internal optical fiber and external cable are connected with ground control station. All components in Belly body are encapsulated after installation.

• The tail part is composed of tail body and tail fin. 14.4V power supply is installed in the tail body to supply power to the overall ROV system; The tail fin imitates the bionic design of the shark and will provide power with the reciprocating swing ofthe tail.

• The joint part is composed of hydraulic system. There are two joints in the ROV. The head / belly joint is responsible for steering and the belly / tail joint is responsible for implementation. The hydraulic system is mechanically driven by servo to twist the joint, so as to provide the driving system under silent working state and the system controlling yaw.

In order to maintain stability, the ROV needs to be naturally neutral in the water, which requires that the center of mass of the robot should be slightly lower than the buoyancy center. In this way, the robot needs to install buoyancy materials outside the body and be wrapped with a streamlined shell, so that the density of the robot is slightly less than that of seawater and reduce fluid resistance. ROV design has three degrees of freedom: yaw, surge and pitch. Due to the need to control the roll degree of freedom of ROV during normal travel, shark fins are installed on the top of the bionic fish bell body, which can automatically correct the attitude according to the fluid resistance on both sides of the.

mechanism when the robot moves forward [5]. The design theoretical pressure of this ROV is 30bars, which is equivalent to the depth of 300m underwater, while the attenuation speed of underwater electromagnetic wave is very fast. The penetration depth of medium wave and short-wave communication is only 10-20m, and the attenuation depth of long wave can reach 100- 200m, but its frequency is low and its signal-to-noise ratio is small, so it is impossible to establish a real-time information transmission system for ground underwater [3]. Therefore, external tether cable is mainly selected for ground communication and picture transmission.

3. Power Mode

In power mode, ROV can provide 10.4 kg forward and 8.2 kg backward by using two T200 thrusters. Thruster includes both clockwise and counterclockwise propellers. Two T200 thrusters are distributed on both sides of the head. The NO.1 servo and the rod is connected by two gears. Therefore, the pitch angle of the two thrusters can be controlled synchronously by the rotation ofthe NO.1 servo.

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Each time ROV restarts, the thrusters will return to their initial position. In order to drive the thrusters, a speed controller like Basic ESC is needed here. Because it is recommended to operate at 12- 16V to obtain the best balance of thrust and efficiency, ESC is directly powered by a 4s Li-ion battery. Each thruster should be connected to an ESC. The ESC should be connected to a signal source and a power source that matches the operating voltage of the thruster. An ESC controls the speed of one thruster, causing the two thrusters to produce a differential speed. A side fin is fixed on the outside of each thruster. As shown in the Fig.1, by controlling the No. 1 servo to change the pitch angle of the thrusters, ROV can be moved in multiple directions. When the thrusters provide vertical thrust, ROV can float up or down. By controlling the differential speed ofthe thrusters on both sides, the rotation function of ROV can be realized. When the thrusters provide horizontal thrust, ROV can move horizontally. As shown in the Fig.2, by controlling the differential speed of the thrusters on both sides, the steering function ofROV can be realized.

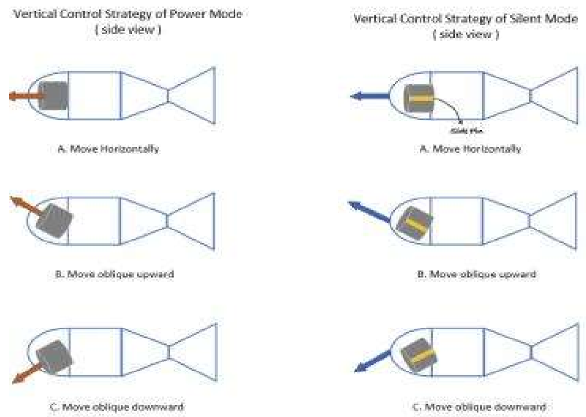

Figure 1. Vertical Control Strategy of Side View (left. Power mode, right. Silent mode)

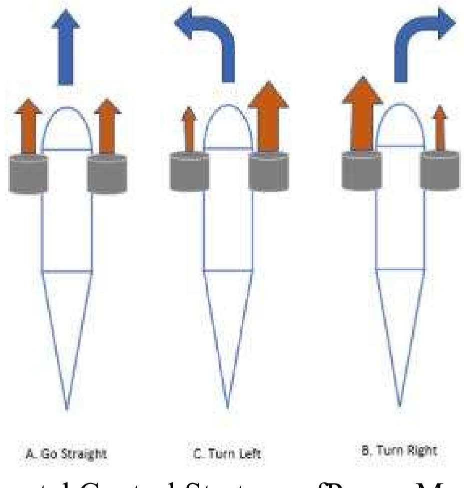

Figure 2. Horizontal Control Strategy ofPower Mode (vertical view)

4. Silent Mode

The silent mode uses the hydraulic system and fin-thruster system distributed at each part of the fish-like bionic ROV body and the angle posture of the servo controls robot with thruster turning off for silent motion.

The hydraulic joint consists of two sets of X-shaped hydraulic lifting mechanisms distributed in left and right directions on the inner side of the joint. The servo uses 7.4V small-power motor and the hydraulic pump uses MZR.3μL mini- gear hydraulic pump, which is operated by the servo to supply

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transmission oil for the hydraulic pump, provides power for two sets of hydraulic mechanisms, each of which consists of small- size hydraulic cylinders, which supply oil to the pipeline along with the hydraulic pump driving by the servo.

By doing that the hydraulic current directly drives the two lateral hydraulic lifting mechanisms to move towards the opposite direction of travel. The whole motion of the ROV by simultaneously contraction/extension of both two hydraulic mechanisms are driven by entire pressure forced on the hydraulic devices, thus it can complete much smoother swifter movement and higher mechanical efficiency of a stroke than traditional connecting-rod mechanism.

4.1 Mechanism introduction

In the silent mode, the robot has two hydraulic / servo movement joints: the robot head / bell joint, which is called steering joint; Robot belly / tail joint, called actuation joint. These two joints have different motor functions. The main features of the two joints are as follows, Fig.3:

• Servo 2 of the steering joint is transmitted by the control platform to the raspberry PI main control chip through optical fiber. The servo of the steering joint sends PWM signals for precise angle control to realize the yawing steering of the bionic robot head, so as to control the motion direction. The user can also send short continuous incremental PWM pulses to realize the non-quantitative yawing of the robot by using the joystick connected to the

control platform, Servo 2 controls one degrees of freedom: yaw. Servo 1 controls the pitch degree of freedom, and the servo 3 controls surge degree of freedom, sum up to 3 degrees of freedom are realized in this ROV collectively.

• Servo 3 of the actuation joint directly drives the actuator of the actuation joint to swing back and forth through the raspberry PI main control chip, so as to control the movement and stop of the robot in the silent mode. When the robot moves in the silent mode, all the power comes from the actuation joint. The hydraulic lifting mechanisms on both sides of the actuation joint contraction / extension back and forth to make the rear end of the bionic robot swing back and forth, simulating the fish driving the tail fin to swing left and right quickly, causing a backward force on the rear water body respectively, and generating a forward thrust with the help of the reaction force, In the whole work process, the working frequency caused by fish tail swing is very low, so the noise is very weak.

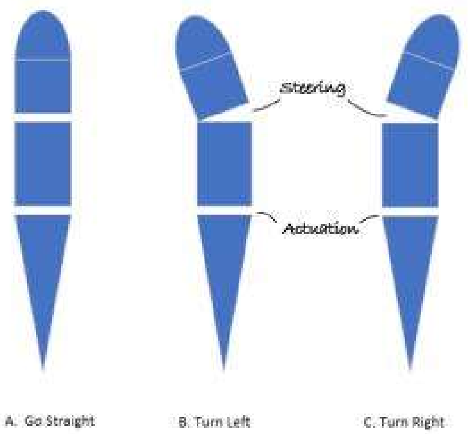

Figure 3. Horizontal Control Strategy of Silent Mode (vertical view)

4.2 Hydraulic system

The main components of the joint hydraulic system are two position four-way hydraulic control directional valve, overflow valve, one-way speed regulating valve, hydraulic cylinder, oil tank and gear hydraulic pump. The working depth of ROV will not be greater than 300m. In the ocean less than 100- 150m, the temperature is always greater than 20 ℃ . When the depth is greater than 150m, it is below the marine thermocline [4], but the temperature will basically be between 0 ℃ - 55 ℃ .

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This is the best working temperature of L-HM anti-wear hydraulic oil, and it is a good choice for the oil circuit requiring reciprocating transmission to produce impact [2]. At the same time, the sufficient heat exchange of the working environment temperature can be used as an effective heat dissipation source for the high- frequency operation of the robot structure to ensure that the hydraulic system is always at the best working temperature. Small scale hydraulic pipeline has small stress concentration factor and stress. Synthetic rubber is usually used, which can effectively reduce the friction of hydraulic components caused by oil circuit impact frequency response [1]. At the same time, the small displacement of the micro hydraulic pump can effectively control the size of other hydraulic components in the system and realize the lightweight structure of the joint. The reciprocating motion and stop function characteristics of the hydraulic system are as follows, Fig.4:

• The hydraulic system can automatically switch the forward/reverse feed state of the system, which is achieved by the hydraulic control switch of the two-position four-way reversing valve controlled by the relief valve. The left position of the reversing valve allows reverse feed and the right position allows forward feed, which is controlled by the NO hydraulic switch controlled by the relief valve. Servo energizes the hydraulic pump to generate pressure when the hydraulic cylinder is actuating regular feed before the hydraulic oil at the outlet is directed to the tank without load, pressuring the oil passage from the inlet branch to the relief valve with low pressure. When the working stroke reaches its maximum, the oil passage stops flowing while the hydraulic pump is still working, which causes the forward feed side pressure of the mechanism to be higher than the prescribed pressure of the relief valve and makes it open, which enables the right position of the hydraulic switch on the reversing valve to realize reverse feed. Similarly, when the reverse feed reaches the maximum stroke, the oil circuit stops flowing, but the reverse feed side pressure increases until it is greater than the pressure specified by the same side relief valve to open the path and open the hydraulic switch of the left position switch to realize reciprocate motion. At the control level, the angle of rotation of the steering joint is determined by the PWM duty cycle; Servo3 on the actuation joint does not need to specify a specific angle, it can achieve motion function by setting an incremental duty cycle in one clock cycle. The incremental adjustment of duty cycle can change the forward speed of silent mode. To prevent suddenly pressure surge or drop when the mechanism operates, one-way speed control valves are installed at the branch connection of two groups of cylinders close to the cylinder body respectively to maintain system hydraulic pressure (valves open with the opposite direction)

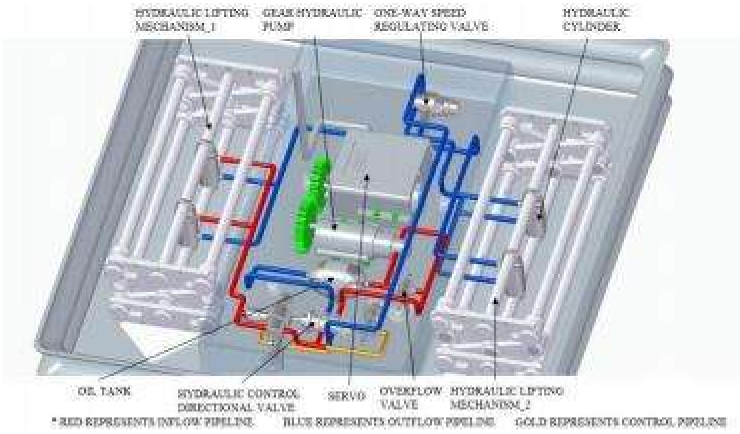

Figure 4. Hydraulic System

• The servo 2 controlled by the PWM wave requires a continuous pulse signal from the main control chip to complete the feed. When the servo 2 moves to the specified position, the PWM pulse stops sending. At this time, the servo 2 stops working, the hydraulic pump driven by the servo 2 stops working at the same time, and the internal state ofthe hydraulic system remains suspended.

4.3 Functioning process

The overall working steps of the silent state system are as follows:

• The ground control station sends instructions and parameters to silent mode via fiber converter to the main control chip of the underwater ROV, including pitch angle, yaw angle and surge speed.

• Optical signal is processed by Raspberry Pi as PWM wave which is transmitted to thruster to turn it off, PWM wave to Servo 1 and Servo 2 to adjust its rotation angle. PWM wave is transmitted to Servo 3 to adjust its rotation speed;

• Servo1 drive the output shaft of the ROV head fin to move and change its pitch angle; Servo drives the hydraulic system at the joint, the hydraulic cylinder bank on one side of the joint feeds forward, and the hydraulic oil is injected into the rod cavity of one group of hydraulic cylinders. At the same time, the hydraulic oil without rod cavity in the hydraulic cylinder is injected into the rod cavity of another group of hydraulic cylinders, which drives the opposite feed of the other group of hydraulic structures and extends the lifting mechanism; similarly, the hydraulic cylinder bank on the other side is injected into the rod. The hydraulic cylinder bank is fed in the opposite direction and the lifting mechanism contracts. The joints bend to one side of the contracting mechanism.

• The steering joint controlled by servo 2 stops moving after rotating to the specified angle within one stroke, and the action joint controlled by servo 3 opens the reversing valve after reaching the maximum stroke to realize reciprocating motion.

• The action joint bends back and forth to drive the tail to swing and push the ROV forward in silence.

4.4 Enclosure

The movable joint of the bionic robot uses the silicone rubber wingfold as the external water barrier material. This wingfold has strong toughness and good hydrophobicity, which can effectively play the role of sealing and underwater work [7]. When in use, it is installed with status of folding and contracting, and its protruding folds are convenient to provide allowance for joint extension. Since the spaces of the bodies on both adjacent sides of the bionic robot joint are encapsulated by organic silicon glue, so only is the sealing of sealing flange and bolt rod needed to be considered here. Overall, there are two places primarily have possibility to leak under water: connection of wingfold, and the connection of body cover plate and joint chuck-flange. The characteristics of two sealing mechanisms used for the moving joint in silent mode are as follows:

• The sealing at the wingfold is completed by Buna-N rubber sealing ring fixed on the sealing flange. In order to prevent assembly error, two groups of four sealing flange plates are used to install between the joint plate on the left and right sides of the joint cavity and the chuck-flange. The chuck- flange is the connector responsible for connecting the joint cavity and the robot body cover plate, and there are chucks around its outer edge, The sealing flange can be provided with installation space. The silicon rubber wingfold is pressed tightly inside of the chuck of the chuck-flange at both ends of the joint. When the sealing mechanism is fixed by enclosure bolts, the rubber sealing ring in the sealing flange is compressed and expanded by the pre tightening force of the fastener to fill the gap to realize longitudinal sealing.

• The sealing of fasteners is realized by O-ring fixed on the enclosure bolt head. The components to be fastened include robot body cover plate, chuck-flange, two sealing flanges and joint plate. Before the bolts fasten whole components with fiber cable installed, the sealing O-ring is fixed on the groove of bolt head on the inner side of bolt head. Consequently, bolt head needs to be loaded directly on the chuck-flange, engaging with the surface of inner hole on the ROV body cover plate. Finally, the enclosure bolt is fastened by threads and nut, and fiber cable through the inner hole is fixed by the plug fasten on the bolt head. Consequently, expansion of O-ring is used to fill the whole inner groove of the bolt head to achieve radial sealing, Fig.5.

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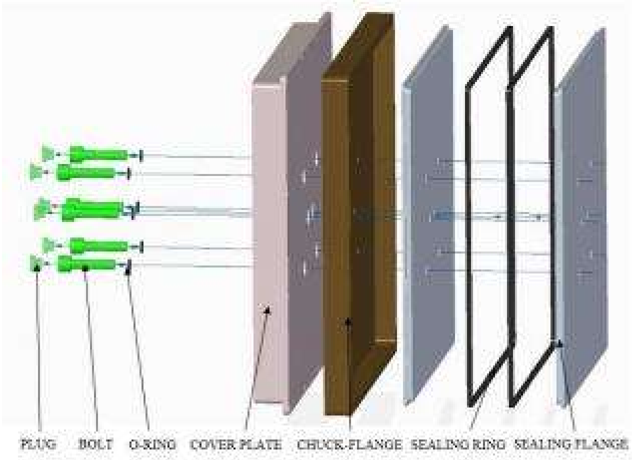

Figure 5. Sealing Mechanism ofConnectors

5. System Description

5.1 Camera system

An IP Camera (IPC) is fixed in a hemispheric-transparent dome which is at the front end of the vehicle. The IPC has two cables, one connected with the DC-DC converter, the other one connected with the fiber converter in the body part ofthe vehicle. The IPC sends image data via an IP network through the cable connected with the fiber converter.

5.2 Sensor system

A depth sensor is fixed at the bottom of "fish's belly" to measure the depth of the ROV. Up to 300m depth of water with a resolution of 2mm can be measured by the depth sensor. The depth sensor can be accessed by the Raspberry Pi through an I2C bus. The sensor also includes a temperature sensor accurate to ±1°C, the measurement of depth can be compensated by the Raspberry Pi using the temperature information.

5.3 Light system

Two 1500 lumen subsea LED lights are of daisy-chain connection and fixed at the front side of "fish's head". The lights are fully dimmable controlled using PWM signal (1100- 1900μs) from Raspberry Pi. The lights are directly powered by a 14.4V Li- ion battery. The brightness ofthe lights is controlled exponentially to fit different-depth environment and the maximum power is up to 15 Watts. The lights have a 135-degree beam angle for wide illumination in front ofthe ROV.

5.4 Propulsion system

The propulsion system uses two T200 thrusters distributed on both sides of the ROV's head part. The thrusters are fixed on the two ends of a roller whose rotation angle is controlled by a servo, so that the thrusters can be adjusted the direction synchronously. The T200 Thruster includes both clockwise and counterclockwise propellers. To drive the thruster, a speed controller like Basic ESC is needed here. Each thruster should be connected with an ESC, and the ESC should be connected with a signal source and the power source that matches the operation voltage of the thruster. One ESC controls the speed of one thruster, so that two thrusters.

can produce differential speeds and make the ROV turn around. Because nominal operation at 12-16V is recommended for the best balance of thrust and efficiency, ESC is directly powered by the 4s Li-ion battery. Every ESC receives PWM signal from Raspberry Pi and transmits a corresponding output to adjust the speed of the thruster. Then the result is the speeds of thrusters are controlled by the Raspberry Pi indirectly.

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5.5 Servo system

There are three servos totally in the ROV. The stall torque of three D30 underwaters servos are 30kg·cm. Their distributions are as shown in the diagram. Servo NO.1, located in the head part of ROV, works as a steering device. This servo is used to control the rotation of the roller which is connected to the thrusters through a transmission. The roller will return to the initial position every time the ROV restarts, when the roller rotates to a certain angle, the thrusters will also synchronously turn to a certain angle in order to make the ROV gain a slant push. Servo NO.2 and NO.3 are respectively at the front articulation and the hinder articulation. They play a role in providing propulsion for the hydraulic system in the articulations. The articulations will twist as the output spline of servo NO.2 and NO.3 rotate. The operating voltage of the servos is 5 to 8.4VDC, so all ofthem are powered by a 7.4V-output DC-DC converter. Besides, the servo respectively receives PWM signals from Raspberry Pi and the output spline will turn to the desired position according to the signal.

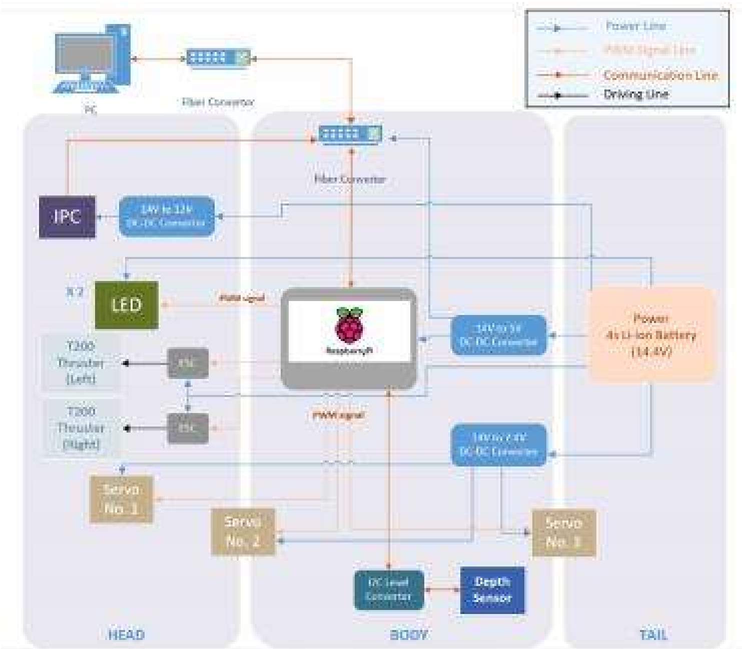

Figure 6. Hardware Connection

5.6 Communication system

Data from surface station travels through a single mode fiber optic cable in the umbilical cable to the underwater vehicle. Both ends ofthe cable are connected to a single fiber media converter. One fiber converter at the surface station is connected to PC, the other one in the ROV is connected to Raspberry Pi. A string of signal is transmitted from PC side to the fiber converter through a copper Ethernet cable. Then the fiber converter translates the electricity into a pulse of light. And the light is transferred over a fiber optic cable in the umbilical cable. The fiber converter in the ROV receives the light signal and translates it back to electrical signal which is then transmitted to Raspberry Pi through an Ethernet cable. From Raspberry Pi to PC is also true.

5.7 Control system

The on-board brain of the ROV is a Raspberry Pi 3 Model B+, with 1.4GHz 64-bit quad-core processor, Broadcom BCM2837B0, Cortex-A53 (ARMv8). The main function of the Raspberry Pi is to deal with the data from sensor and transmit it to PC, as well as control the servos, thrusters and LED. The Raspberry Pi is connected with the surface station using Ethernet and with the sensor using I2C communication.

5.8 Power supply system

The main power supply device is a 4s Li-ion battery which is located in the tail part of the ROV. There are three DC-DC converters in ROV to decrease the output voltage of the battery to suit the operating voltages of other devices. Their output and distribution are as shown in the diagram, Fig.6.

6. Conclusion & Further Work

This thesis gives a detailed description of key mechanisms would be necessarily installed in order to design an underwater remotely controlled bionic robot, and shows the whole working process of our solution in machinery part and electronic control system to complete the task ofunderwater inspection and shoal monitoring, which has capacities to achieve various operation modes, flexible mobile control, compact lightweight distribution, bionic fish appearance and adequate functioning auxiliary system. As there have not been more widely successful research ofthe certain kind ofROV, our solution would be a better choice for the development of a bionic fish ROV.

In further work, we will manage to adapt more efficient utilities upon the electronic system, and enhance interaction of digital devices between ground control and underwater sensors such as sonar and high-resolution camera feed, in order to make it more specialized for scientific research and industrial use. Furthermore, we are going to hand on the hardware and power source update, replacing with more powerful DSP, higher capacity, power supply and acoustic communication transmitter to realize autonomous navigation (AUV) in the future.

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