Design for Navigation of Underwater Remotely Operated Vehicle

Yashas Shetty[1], Saurabh Shetty[2], Arnav Wayade[3], Ekta Akadkar[4]

[1,2,3,4]Maharashtra Institute of Technology, Pune, Maharashtra, India

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Abstract - This paper presents a design of the mechanical and electronic system for navigating an Underwater ROV providing 6 degrees of Freedom. The system consists of thrusters, a ballast tank and, a movable float.

The paper provides an insight into each part shown in the schematic figure below. The mechanical aspect is described followed by its electronic aspect. Integrating these parts forms the navigation system for the ROV. Further, there is a description of the telemetry of the Remotely Operated Vehicle (ROV).

Keywords: ROV, Float, Ballast, Thrusters

INTRODUCTION:

A remotely operated vehicle (ROV) is an unoccupied underwater robot that is connected to a ship by a series of cables. These cables transmit control signals between the operator and the ROV, allowing remote navigation of the vehicle. ROVs are used for deep water unmanned operations. ROVs are maneuvered using thrusters and ballast tank in all the required directions. ROVs may include a video camera, lights, sonar systems, and an articulating arm. The articulating arm is used for retrieving small objects, cutting lines, or attaching lifting hooks to larger objects.

The ROV described in the paper is designed to have the freedom to move in all six degrees of motion. It contains two articulating arms one having a working arm functionality and the other used for grabbing supports. It is capable of bearing the two robotic arms (the articulating arms) and stabilize itself during their operation. It has a movable float for balancing and thrusters for horizontal motion, vertical motion and rotation about Z-axis

The electronic system aims to be reliable and robust at the same time. Integration of the major components for the navigation system, include thrusters, pumps, valves, etc. Along with the control systems, power supply design and execution is also an important aspect. Also, the heat dissipation of all the electronic components should be looked after in the design stage itself.

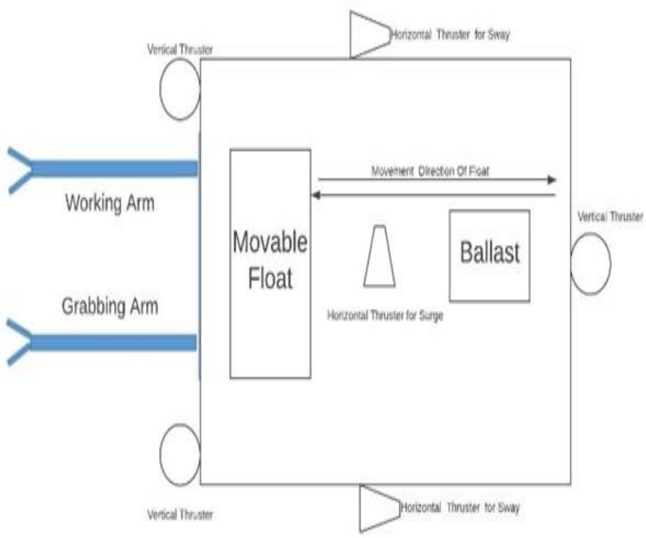

Figure-1 Schematic of the ROV

BALLAST TANK:

A ballast tank is used to control the depth of the ROV. Initially, to lower the ROV into the water, water is allowed to flow into the ballast tank. A solenoid ON-OFF valve was used to control the flow of water flowing inside the ballast. This increases the average density of the object and the ROV sinks into the tank up to the point where the average density of the object is equal to the density of water. For lifting the ROV, the water is pumped out from the ballast tank, using a pump, which is to be fitted with a non-return valve to restrict the entry of the water into the ballast through the pump. Provision is made for an air vent so that atmospheric pressure is maintained inside the tank.

The continuous flow of water into the tank is controlled by changing the duration for which the shut-off valve is on.

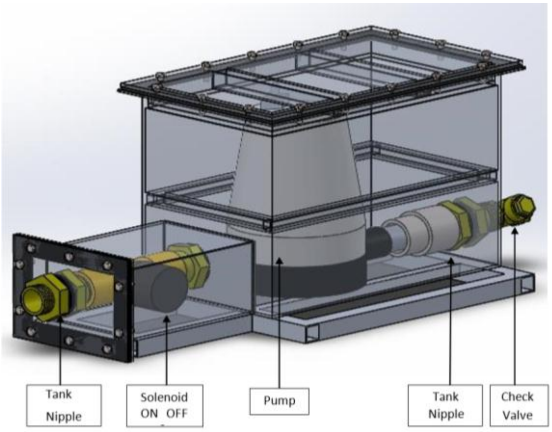

Figure-2 3D CAD model of the ballast tank system

The ballast consists of two actuators, a pump, and a valve. The pump consists of a PMDC motor. A PMDC motor matches the requirements and it is to be rotated in only one direction. This makes its driving circuitry very much simpler.

A solenoid valve is used for the operating the valve electronically. It is the most simple and economical option available for a valve.

The pump needs to be driven in only one direction, thus using even a single MOSFET is sufficient. Giving a PWM signal to the MOSFET would control the speed of the motor. Hence a MOSFET would seem to be a good option for driving the pump. The valve requires only two states, ON and OFF. Hence a switching element is required. It is not necessary that the switching frequency of the element should be high. Thus, a relay can be used for operating the valve as well.

For controlling the depth algorithms like Continuous Input Smoother and Discrete Fuzzy Smoother [1] can be implemented on this system.

BALANCING OF ROV:

If the Centre of Buoyancy(CB) is not above the Centre of Gravity(CG), the ROV will rotate[2]. When any (or both) of the arms move, the CG of the ROV changes causing an imbalance.

The balancing is achieved by shifting the CB exactly above the CG. A highly buoyant material called as the float is used. The float is mounted on a lead screw. It is moved along the leadscrew which changes the CB of the ROV, thus balancing it. Its position needs to be moved accurately.

For instance, when the arms are extended, the CG shifts by 93mm in the positive Z-direction. This will cause an imbalance in the ROV and to counteract that the movable float needs to be moved in the positive Z- direction by 400mm to shift the CB above the CG again shown in Figure-3.

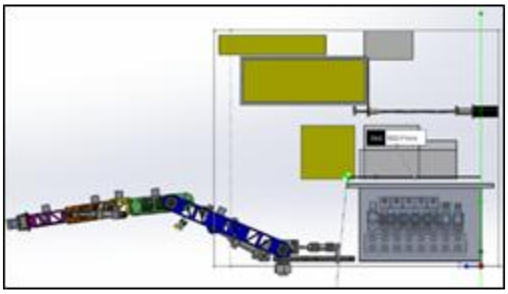

Figure-3 ROV in extended position of arms,

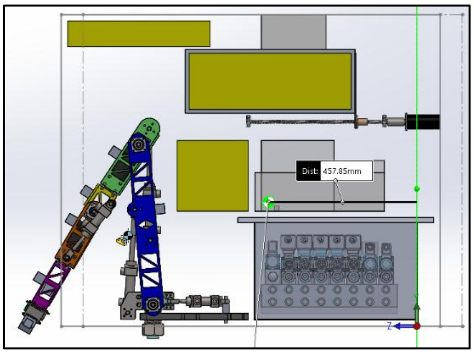

Figure-4 ROV in the retracted position of arms

This is achieved by using a lead screw assembly driven by a stepper motor (Part no. of motor BH57SH51-2804A)

A stepper motor has precise position control as compared to other DC motors. This characteristic perfectly fit the requirements. Thus, we decided to use a stepper motor for moving the float. For further minor corrections, thrusters are used.

Similarly, for controlling a stepper motor, pulses in a specific sequence are required. Also, the frequency of the pulses is responsible for the speed of the motor. Moreover, different is logic is required for operating the motor in micro-stepping mode. Hence it is advisable to use a driver which will handle these operations

THRUSTERS AND POSITIONING:

The thrusters provide the motional thrust for the whole ROV. Thus, it requires a lot of power. A PMDC (Permanent Magnet Direct Current) of such specification would be bigger in size as compared to a BLDC (Brush Less Direct Current). Also, the heating of a PMDC is more than BLDC due to the brushes present in it. The brushes also reduce the efficiency of the PMDC motor. Hence use of a BLDC thruster is the best option. We selected the T200 thruster by Blue Robotics for the purpose.

Thrusters can be positioned in many ways like this ROV[3], or if we need it to have surge, heave, and yaw then it can be like the Kaxan ROV[4]. The positions in our ROV are much similar to this one[5].

To achieve translatory motion along all the 3 axes and roll, pitch and yaw corrections, 6 thrusters have been used. This is the minimum number of thrusters required to achieve all 6 degrees of motion. The placement of the same on the ROV is as shown in the images below.

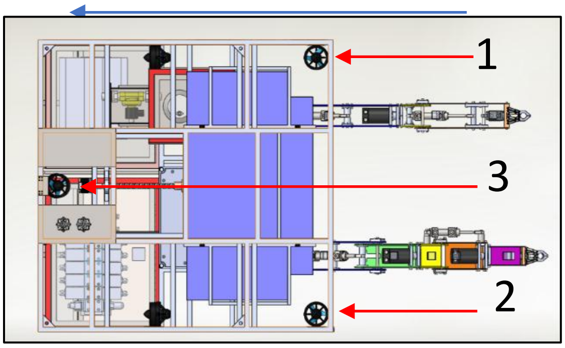

Figure-5 Thruster Positioning - Top View

Three thrusters at the top of the ROV are used for minor up and down motion. These thrusters are also used for pitch and roll corrections of the ROV.

The thrust given by thrusters 1 and 2 will decide the roll angle of the ROV. Thruster 3 along with 1 and 2 will effectively decide the pitch of the ROV

Two thrusters (4 and 6) at the mid-level of the ROV are used for front and back motion of ROV as well as the yaw motion. A single thruster (5) below the electronics box is used for lateral motion of the ROV.

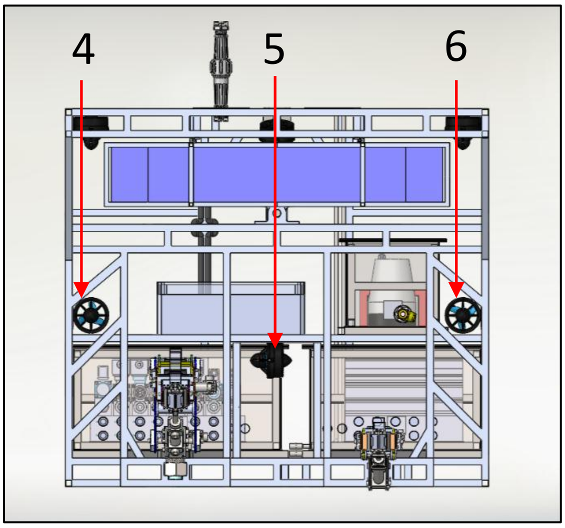

Figure-6 Thruster Positioning - Front View

THRUSTERS AND TESTING:

The maximum thrust required by any of the thrusters was calculated by analyzing all the forces acting upon the ROV, the position of the center of gravity and center of buoyancy, etc.
The required thrust came out to be 2.75 KgF
The thrusters were tested to make sure that they suffice the requirement. The testing procedure was similar to the testing described here.[6]

ON Time(microseconds)	Thrust
1100	2.891
1200	1.486
1300	1.032
1400	0.313
1500	0
1600	0.342
1700	1.528
1800	2.519
1900	4.13

Table-1 Thrust w.r.t. ON time

The observed thrust was sufficient to navigate the ROV, hence we proceeded with the thruster. Table-1 has the results

The thrusters are controlled using an electronic speed controller. The thruster consists of a three-phase BLDC motor. For driving the BLDC motor, a three-phase signal is required. An Electronic Speed Controller (ESC) generates these required signals. The input for the ESC is a single PWM signal.

According to the ON time of the PWM signal, the direction and RPM of the motor is determined. The ESC itself manages the timing required for generating the three-phase signal at the output of the driver. Instead of using an ESC, if we use three half bridges for controlling the motor, the controller which sends signals for controlling the half-bridges will have to maintain the phase difference for the signals. This would require significant processing. Thus, an ESC is used for controlling the thrusters. Basic ESC by Blue Robotics is used here.

HEATING OF THE SYSTEM:

The digital system requires very less amount of current for its operation. Hence it does not produce any heating problems even after long hours of operation.

The pump requires around 8 to 9A current in continuous operation. It is operated using a relay which is rated for much larger values of current. Hence no heating was observed there as well.

The stepper motor requires 2.8A at maximum load. Drivers rated at 6A are easily available. Hence there isn't any heating problem with that as well.

The driver for the thruster i.e. the ESC would draw an equal amount of current as that of the thruster. Hence the power dissipation would be large.

The MOSFET used in the ESC is IR 5301.The max resistance (Rds) of the MOSFET is 1.2 milliohm.

If 25A current flows through the ESC, the power dissipated will be
P = (I^2) *R
P=0.75W

We tested the ESC at full load so that maximum current (which was observed to be 22A) will flow through it. Its temperature was noted until it reached a stable point. The observations are noted in Table-2

Table-2 Temperature of ESC w.r.t. time 1

time (mins)	temperature(^{o}C)
10	35
20	42
30	49
40	52
50	57
60	58
70	59
80	59
90	59
100	59

The ESC was enclosed in a metallic box and its heat sink was stuck (using thermal pads) to the box for better heat dissipation. The testing was done again and the ESC functioned for about 2 hours.

Hence the heat dissipation for the system was concluded.

TELEMETRY:

Digital side of the system.

Along with the thrusters, a stepper motor and a pump which are the actuators, the ROV has a pressure sensor and an IMU and cameras as its feedback. There is a 25m tether between the operator and the ROV. Hence a long-distance communication method is essential for data transmission. The ROV and the operator need to communicate on a real-time basis. Methods for communicating with Underwater Vehicles can be wireless or wired. Wireless communication can be done by using light or sound[7]. Wired communication is very much efficient than wireless ones. In wired ones, TCP/IP is designed for reliable channels and high-performance communication.[8]Thus, we have used the TCP-IP protocol for this communication. An ethernet cable (CAT6) is used for connecting the system to the operator. TCP-IP is the simplest and most reliable for long-distance transmission.

As we are using TCP-IP, and we need to control the actuators as well along with the getting feedback from the sensors, using a single controller won't be feasible. Using TCP-IP and cameras themselves require high processing. A raspberry-pi is used for the purpose. For driving the actuators and receiving feedback from the sensors (pressure sensor and inertial measurement unit) the Atmega 328P is used. The Atmega 328P has the required peripherals for driving the actuators namely Pulse Width Modulation, multiple timers, and sufficient GPIOs. It can communicate using the I2C protocol which is required for the sensors. Generating pulse required for the thrusters and those for the stepper motor is also very convenient in the Atmega328P.

Thus, the operator communicates directly with the raspberry pi and receives the visual feedback (of the cameras) and communicates with the Atmega 328P indirectly (via the raspberry pi) for driving the ROV and getting the sensor feedback.

POWERING THE SYSTEM:

Generally, an ROV needs to be operated for at least 2 hours. Moreover, the operator is far from the vehicle.

There are two options for powering the system

1) Using Batteries
2) Using a power supply

There is a trade-off in using anyone of the above.[9]

Advantages of using batteries

Batteries are a portable energy source. Essentially, they convert chemical energy to electrical energy. They are compact and thus can be placed inside the machine (in our case the ROV).

Hence the need for a cable for powering the ROV is eliminated thus removing the complexities of cable drop and cable heating. Also as compared to an SMPS power supply, the noise generated is also less. Thus, powering off the system in case of emergency would not be possible.

Advantages of power supply

A power supply provides a constant voltage at the output, whereas the voltage of the battery is dependent on the charge of the battery. The ROV needs to be operated for hours, a battery won't sustain for that long. On the other hand, a power supply does not need to be charged. It can be operated for hours. A very crucial advantage of the power supply is that the switch of the system is present near the operator. Thus, powering off the system in case of emergency would be possible. Importantly, a power supply would be grounded to the earth, thus stabilizing the ground loop.

Therefore, we decided to use power supplies for the purpose.

There are 2 operating voltages at the power side of the system. Both require high currents. The thrusters which operate at 16V require a cumulative 150A. Whereas the pump, stepper motor, solenoid valve, DCVs, Proportional DCV require a cumulative 40A.
The digital side operates at 5V requires around 5A.
As current the requirement of the digital side is less, we decided to use a buck converter to supply 5V. To reduce the dropout voltage at the buck converter,16V input is used for the buck.
Hence the specifications for the 2 supplies and the approximate current required by the loads are listed below.

Specification: 16V, 160A
Load requirements
1. ESC: 25 A * 6 = 150 A
2. Raspberry Pi, Arduino = 5A

Specification: 24V, 20A
Load requirements
1. Bilge Pump: 9 A * 1 = 9A
2. Stepper motor: 3 A * 1 = 3A
3. Solenoid Valve: 3A * 1 = 3A

Generally, in ROVs, a single supply of 48V is used.
In the above scenario, if we use a 48V supply, approximately 70A would be required.
Moreover, 2 buck converters of high current (like the CDS40048) would be required to convert 48V to 16V and 24V. This would be inside the ROV. The cost for high current buck converters is very high. It proved out to be more expensive than buying 2 power supplies.
Moreover, it would increase the complexity of the electronic system. Also placing such high-power components in the ROV increases the risk factor of the system.

Cable Drop

As we are using a power supply to power the ROV system, the power will be delivered by a cable. The current requirement of the system is very high. Also, the cable is quite long for DC supplies. And the power is of DC form. Thus, there will be a significant drop in the potential of the cable. Also, the power loss in the cable will be significant.
Hence, we decided to use several wires in parallel. So, we calculated the amount of current that each wire can handle. We calculated this from its given power rating and diameter.
The power rating of a general multi-strand wire is around 40W. We choose wires whose diameter is 3.2 mm

The resistance of a conductor is given by:

R = rho*length/area

rho = conductivity.

The cable length is 25m. As we were using copper wires, rho = 1.68e-10.

area = pi*(d^2/4)
pi=3.14

The diameter for each wire is 3.2 mm
Hence
Area = (3.14*3.2*.2/4)*1e-8
= 8.0384e-8
Thus
R = 25*1.68e-10/8.0384e-8
R = 0.0522 ohm
The power rating is 40W

Now,
P = I^2*R.
P = Power dissipation
I = Current
R= Resistance of conductor
Hence
I = sqrt(P/R)
I= sqrt (40/0.0522)
I= 25.2A

Thus, each wire will be able to conduct 25.2 A
Hence, for a total of 160A,
We will require 160/25.2 = 6.34

Hence, we require 7 pairs of parallel wires. This would be for one terminal (i.e. positive or negative). For the other terminal, another 7 wires would be required. Thus 7 pairs of wires would be required the 16V, 160A supply.

For the 24V, 20A supply, a single pair of wire would be sufficient (as one wire can handle 25.2A).

CONCLUSION

The mechanical and electronic system of the ROV has been designed. This ensures that the ROV has all six degrees of freedom motion. All the requirements for the same have been informed. Firstly, individual testing of all the components was done. All the parameters were taken under consideration such as heating of the ESC and control system requirement of the motors, etc. The actual conditions were simulated during the testing of the individual component.

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