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## Problem Identification for Underwater Remotely Operated Vehicle (ROV): A Case Study

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### Abstract

This paper investigates and describes problem identification of Unmanned Underwater Remotely Operated Vehicle (ROV). The following is the problem identification that found after research done on several literature reviews and study cases. In this paper, the major problem statements will be discussed in details such as control system, underactuated condition, pose recovery or station keeping, coupling issues and communication technique. ROV is one of the Unmanned Underwater Vehicle (UUV) tethered with umbilical cable and remotely operated by a vehicle operator's. Control system of ROV is a bit complex because of the unknown non-linear hydrodynamics effects, parameters uncertainties and the lack of a precise model of the ROV dynamics and parameters. Conventional controller cannot dynamically compensate for unmodeled vehicle hydrodynamic forces or unknown disturbances. Underactuated condition is defined as one having less control inputs than degree of freedom, so how the ROV want to maintain a certain point or depth following mission when one or more of thrusters malfunction also an issue to be highlighted. Pose recovery or station keeping will be one of the issues in ROV design. This station keeping approach is used to maintain a position in relation to another moving ROV as the ROV tries to remain stationary at the desired depth with present the environmental disturbances such as wind, waves, current and unexpected environmental disturbances. Coupling issue between the tether and cable with ROV body will be one problem in stabilizing the ROV itself as it double the vehicle load. . The underwater vehicle size, weight and operating depth, as well as the underwater vehicle motors, subsystems, and payload, all combine to determine the ROV's cable design. In underwater, the inability of wireless communication system fails to work very well to transmit the video stream even in short distance is another issue to be covered. This statement proved by Underwater Technology Research Group student's project. The experiment sets up three types of sensor using wireless communication system for higher frequency such as video stream, data transfer and GPS.

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*Keywords:* Remotely Operated Vehicle (ROV); Control System; Cable Coupling; Pose Recovery; Underactuated Condition; Communication technique

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### 1.0 INTRODUCTION

Peninsular Malaysia covers a very large area of coastal seas. In the year 2020, there will be a lot of ports for ships and other sea-vehicles. The motivation of this research is that it is impractical to manually explore the underwater section of the ship anchored or waiting to be docked [1]. Immediately inspect the cracks on ship underwater would reduce unwanted risk. Exploring partial underwater environment is dangerous and impractical for human, especially in precise tasks or needs more time to complete the task [2- 4]. A ROV is a tethered unmanned underwater robot. They are common in deepwater industries such as oil and gas exploration, telecommunications, geotechnical investigations and mineral exploration. ROV may sometimes be called Remotely Operated Underwater Vehicle to distinguish it from remote control vehicles operating on land or in the air.

ROV are unoccupied, highly maneuverable and operated by a person aboard or vessel. A ROV is essential as an underwater robot that allows the vehicle's operator to remain in a comfortable environment while the ROV works in the hazardous environment. The ROV system comprises underwater vehicle, which is connected to the control platform and the operators on the surface by an umbilical cable, a handling system to control the cable dynamics, a launch system and an associated power supplies. ROVs can vary in size from small vehicles with video's for simple observation up to complex work systems, which can have several dexterous manipulators, TV's, video cameras, tools and other equipment [6]. Effective control schemes require relevant signals in order to accomplish the desired positions and velocities for the vehicle. A suitable controlling method of underwater vehicles is very challenging due to the nature of underwater dynamics [7 - 11]. In this project, the focus will be in controlling an ROV in a multi-axis motion in order to maintain its desired position. Fig. 1 shows the examples of micro ROV. We plan to develop one Micro ROV for depth control.



Fig. 1: Examples of Micro ROV develop by UTeRG

Below is the advantages and disadvantages of ROV system in general view. Some of the advantages of an ROV are as follows:

- No time constraints (power supplied on board a different vessel)
- Able to cover wide areas (relative to capacity of human divers)
- Mobility allows close-up examination of sea bed
- Deployment areas less restricted than towed video. Can be used in areas with submarine obstacles.
- Some models are able to collect benthic (the ecological region at the lowest level of a body of water such as an ocean or a lake) samples

The disadvantages of ROV such as:

- Depth range limited by length of umbilical cable.
- Equipment needs a hard boat to operate. May be unable to access very shallow waters.
- Equipment is very expensive and not widely available.
- May be difficult to employ in areas with strong water currents.
- Sampling is non-random for example areas for observation and is selected by the operator.

Table 1: Summary of ROV categories

Class	Capability	Power (hp)
<b>Low cost small ROV/ mini or micro ROV</b>	Observation (<100 meters)	<5
<b>Small ROV (Electric)</b>	Observation (<300 meters)	<10
<b>Medium (Electro/ Hydraulic)</b>	Light/ Medium Heavy Work (<2,000 meters)	<100
<b>High Capacity Electric</b>	Observation/Light Work (<3,000 meters)	<20
<b>High Capacity (Electro/ Hydraulic)</b>	Heavy work/Large Payload (<3,000 meters)	<300
<b>Ultra-Deep (Electric)</b>	Observation/Data Collection (>3,000 meters)	<25
<b>Ultra-Deep (Electro/Hydraulic)</b>	Heavy Work/Large Payload (>3,000 meters)	<120

The ROV's system is shown in Fig. 1. This ROV called SMART-ROV was developed by Underwater Technology Research Group, Faculty of Electrical Engineering, UTeM. Modern ROV systems can be categorized by size, depth capability, onboard horsepower, and whether they are all-electric or electro-hydraulic. In general, ROVs can be grouped as follows in Table 1. Small vehicles includes the majority of "low-cost" ROVs (LCROV), most of which are typically all electric and nominally operate to water depths of 300 meters as shown in Table 1. "Low cost" is relative and vehicles in this class sell in the USD 10,000 to over USD100, 000 range. These vehicles are used primarily for inspection and observation tasks such as pipe/ship inspection, surveying and bottom profiler. Its special use is normally for military applications.

## 2.0 CONTROL SYSTEM

Control system of underwater vehicles is not easy, mainly due to the non-linear and coupled character of plant equations and also the lack of precise model of underwater vehicles dynamics and parameters, as well as the appearance of environment disturbances [6]. The automatic control of underwater vehicles represents a difficult design problem due to the nature of the dynamics of the system to be controlled. Controllers based on simple models of vehicle mass and drag usually yield disappointing performances [10]. Recently depth control methods of unmanned underwater vehicles are given in Table 2.

Table 2: Control method with limitations

Control Method	Limitations
PID	Cannot dynamically compensate for unmodeled vehicles hydrodynamics forces or unknown disturbances Parameter configuration contradictory between response speed and overshoot control.
Sliding mode	Could easily lead to system jitter and effect control accuracy
Fuzzy	Hard to tune the fuzzy rules. Overshoot prediction time not smoothed
Neural Network	Cannot meet the requirement of rapid response Complex for real time application

The underwater vehicles control is difficult because of the unknown non-linear hydrodynamics effects and parameter uncertainties and difficult to estimate accurately. The general underwater vehicle control system design problem includes a variety of nonlinearities and modelling uncertainties. These include hydrodynamic nonlinearities, inertial nonlinearities, and problems related to coupling between the Degrees of Freedom (DOF). The automatic control of underwater vehicles represents a difficult design problem due to the nature of the dynamics of the system to be controlled. Controllers based on simple models of vehicle mass and drag usually yield disappointing performances. Simple control techniques such as PID control have been more commonly used because of the relative ease of implementation. A PID tracking controller has been implemented successfully on an UUV [11 - 14]. The controller is an extension of the control technique of computed torque control which is used in robotics.

Simple Linear Quadratic Gaussian controllers have also been developed [12]. Despite the existence of these simple controllers, other more complex control techniques have also been recently utilised for UUVs. Fuzzy logic controllers have been proposed and implemented with success on UUVs in several cases [13][18]. The nature of fuzzy logic offers a control solution when a mathematical model is not well known, or not known at all as the case may be. Thus, implementing a controller on an UUV using fuzzy logic can avoid the need for complex hydrodynamic modelling of the vehicle. However, the downside is this implementation on the controller itself poses its own level of complexity. The SIFLC (Single Input FLC) is then applied to control the depth of UUV. The simulation reveals that the SIFLC has excellent performance and it exactly resembles conventional FLC in terms of its response. The main advantage of SIFLC is the reduction of the system to SISO [18]. However, up to this point, the SIFLC has never been tested on an actual UUV. Adaptive control has also been used, [16], with the benefits of this type of control obvious due to the changing dynamics of UUVs in the ocean. For example, the controller can adapt itself to varying ocean currents or to a different vehicle density when ballast tanks are used. Adaptive control is also useful because UUVs are usually refitted with new equipment such as manipulator or vision system and adapted for different missions which change their static and dynamic characteristics. Another technique that has been used is sliding mode control [21]. In this control scheme, the dynamics of the system are altered by the application of high-speed switching control [21]. The system is in essence constrained in such a way so as to exhibit desirable characteristics. This proves useful in the linearization and hence, controlling of underwater vehicle dynamics.

The different control techniques discussed have more commonly been used in combination with each other. For instance, a neuro-fuzzy controller has been developed by Qian Liu [23] for modelling attitude control for an UUV. This involved using a combination of neural networks and fuzzy logic. Salman et al. [22] on the other hand implemented a sliding mode adaptive control system for controlling an UUV. The uniting of these different control techniques brings about the advantage of combining the useful properties of each one to improve the robustness and fault tolerance of the overall controller. This literature summarizes several existing work in controlling of the underwater vehicles. Various control schemes employed to control these vehicles are presented, which has been studied for years that can be used to stabilize the motion of ROV.

## 3. UNDER ACTUATED CONDITION

Underactuated conditions is define as one having less control inputs than degree of freedom. In some underactuated system, the lack of actuation on certain directions or depth can be interpreted as constraints on the acceleration. For ROV, underactuated condition means when one or more of thrusters malfunction. The ability of to maintain a certain path or depth in its mission is addressed by having two thrusters used for depth control, if one of thruster malfunction, the second

thrusters will take over the control.. At this moment, for the first stage, the two thrusters will move with 6 V supplied to submerge a certain depth, then if it has malfunction, another thruster will be take action to control the depth by increasing the supply to 12 V.

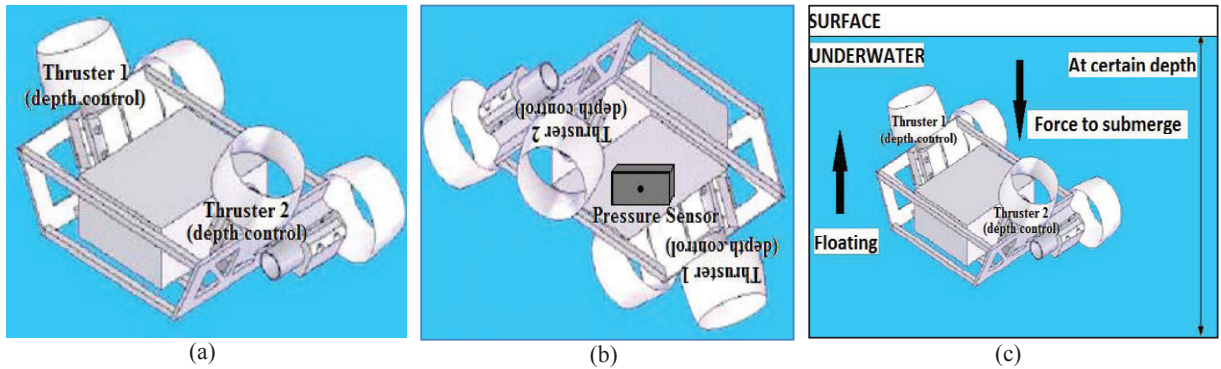


Figure 2: Device configuration; (a) Thruster configuration for depth control, (b) Pressure Sensor configuration, (c) Scenario only one thruster works

Fig. 2(a) shows the thrusters configuration for the depth control. For example for depth operation for certain set point using two thrusters (Thruster 1 and 2 showed in Figure 2(a)) supplied by 6 V DC motor. The thrusters will submerge for certain depth. Then suddenly, one of thruster broken or loss connectivity, another thruster will take an action to control a depth which increasing the value of supply such as 12 V to maintain at certain depth. The pressure sensor in Fig. 2(b) will be attached near to the two thrusters for stability purpose. For initial stage the pressure sensor will sense the pressure to determine the depth.

After that the thrusters will operated based on pressure sensor reading. If we set the depth at 5 meter deep, the thrusters will thrust or submerge until it reach set point and try to maintain set point. The conventional proportional controller will control the thrusters submerge follows the set point. Maybe stability of ROV will be uncontrollable but still submerge at certain depth. This mean angle of ROV will be skews to horizontal angles depends on which one thruster still works as shown in Fig. 2(c). Another problem will be occurred on this part the location putting the pressure sensor. The pressure sensor should attach on the centre between two thrusters so that it can balance their speed of thrusters. The best solution that we can see every thruster must have encoder to derive it speed of thrusters. So, we can count the speed of thrusters, suppose thrusters will get same speed depends on pressure sensor. If one of thruster not follows the speed the set the ROV will be unbalance.

#### 4. STATION KEEPING

Pose recovery or home-keeping/station keeping will be one of issue in ROV. With environmental disturbances (wind, waves and currents) and unexpected environmental disturbances such as strong waves, how the ROV will be recovery or station-keeping. Fig. 3(a) shows the path planning for ROV at certain depth. How our ROV will come back to home position after it in set point position. The ROV will do the task given based on following path. Suddenly between the paths have an obstacle or other environmental disturbances the ROV move out from the planning path as shown in Fig. 3(b). How can it back to the following path? Or when ROV complete all the given task, it can go back to home position using the shortcut way compared follow the following path if no other new task given. So it can save the power requirement and time to travel back to home position. After complete a task at set point will floating to surface and communicate using GPS for navigation. After get a feedback from GPS and ROV will calculate the shortest distance back to home position.

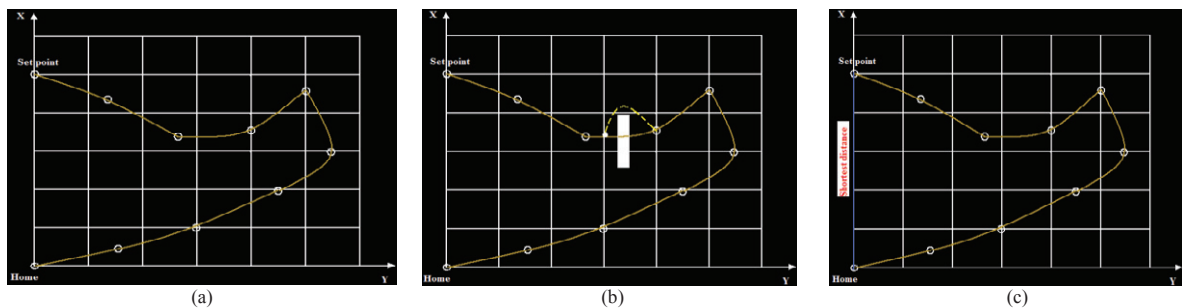


Fig. 3: (a) Path planning; (b) Environmental disturbances in planning path and (c) Shorter distance from set point and origin.

## 5. COUPLING ISSUE

ROV is tethered with umbilical and remotely operated by an operator. Coupling issue between tether and cable with body of ROV will be one of problem in stability of ROV. Most ROVs require a cable to transfer the mechanical loads, power, and communications to and from the underwater vehicle. This will be coupled load to Underwater Vehicle (UV) load as shown in Fig.4(a). The UV size, weight, operating depth, UV motors (thrusters), subsystems, power, signal, strength requirement and payload are the parameters to be consider in designing ROV's cable. There are two general categories for cable: umbilical cable (ship to the ROV or tether management system (TMS)) and tether cable (TMS to the ROV). Standard ROV use an electro-mechanical cable.

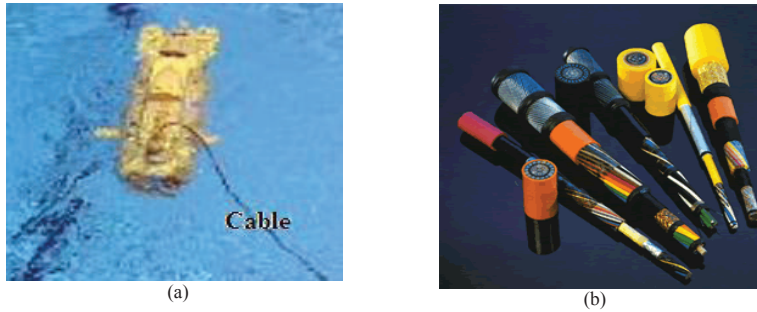


Fig. 4: Cable used for ROV, (a) Cable with body of ROV; (b) inside of ROV cables

This cable actually will be effect the dynamics and stability of ROV. So how we can reduces the size of cable for ROV application. Among researchers, sensors used were powered by battery inside the ROV, while thrusters and video transmission were powered by power supply from the station.

## 6. COMMUNICATION OF ROV

Inspection, monitoring and video transmission will be important part based on ROV application. In underwater wireless communication for higher frequency fails to work well due to very limited distance can transmit the video stream. This proved with experiments done by UTeRG (Underwater Technology Research Group) student's project. Three types of sensor using wireless communication system were developed such as video, data transfer and GPS. All the experimental done can conclude that wireless communication system for higher frequency fail to works well on underwater. Table 3 shows the data information of the GPS consists of the numbers of SNR when the experiment done in open surfaces. The maximum depth can be received the signal is about 8 cm. From the Table 3, we can see that the GPS receiver cannot receive the signal in more than 8cm deep underwater. Signal strength is strong on the surface because the average number gives by the SNR is the highest that was 32dB. The signal becomes weak when the GPS receiver is placed on underwater because the signal cannot pass through. At this point, we can say that the signal strength is inversely proportional to the depth.

Table 3: The data information of the GPS

NO	Depth below water surface (cm)	Average SNR (dB)	No of channel available	GPS Quality (mode)
1	0 and above water surface	32	9	3D SPS
2	1	22	6	3D SPS
3	2	16	7	3D SPS
4	3	20	4	3D SPS
5	4	16	4	3D SPS
6	5	15	4	3D SPS
7	6	17	3	2D SPS
8	7	15	3	2D SPS
9	8	17	4	2D SPS
10	9	19	1	Invalid
11	10	21	1	invalid

The signal strength was determined by the average value of Signal to Noise Ratio (SNR), (dB) and relative to the mode of GPS quality that was the 3D SPS mode, 2D SPS mode and NoFix mode or invalid. If the number of SNR is high and the GPS quality is 2D SPS, this signal is not accurate because the 2D SPS shows that there are not enough messages from satellite for navigation message measurement to determine the position. The GPS navigation message contains information that is necessary to perform navigation computations [2]. To get the accurate positioning, the GPS receiver must receive the signals from satellite. There must be at least 4 satellite channels with SNR value available [2]. If the channel available is less than 4, the positioning of the GPS location may not be accurate.

Table 4: Range Test

TYPE OF TEST	RANGE (meter),(m)	DEPTH OF SIGNAL RECEIVED (meter),(m)	TIME DELAY (second),(s)
Surface	1	-	0
Underwater		0.4	0
Surface	2	-	0
Underwater		0.37	0
Surface	3	-	0
Underwater		0.37	0
Surface	4	-	0
Underwater		0.30	0
Surface	5	-	0
Underwater		0.25	0
Surface	6	-	0
Underwater		0.20	0
Surface	7	-	0
Underwater		0.15	0
Surface	8	-	0
Underwater		0.10	0
Surface	9	-	0
Underwater		0.10	0
Surface	10	-	0
Underwater		0.10	0

Table 4 shows the result of range testing for different depth ranges from 1 meter to 10 meter between transmitter and receiver. The type of test is on underwater. The result also shows that the time delay of the data transmission is zero second. These indicate that the transmission time is very small and too difficult to measure and calculate. Table 4 explains that at 1 meter range between transmitter and receiver, the maximum depth from the water surface that a receiver can sink is 0.4 meter. A depth further than that leads the receiver unable to acquire any signal. When the range between transmitter and receiver is increased slightly, the depth of receiver will decrease slightly that is closer to the surface of water. The results show that range of transmitter and receiver is inversely proportional to the depth from surface of water [3].

## 7. ANOTHER PROBLEM

The dynamics of the thrusters dominate the control problem and must be properly considered. Additionally, the ability of thrusters to produce force is greatly influenced by axial- and cross-flow effects nonlinearities related to thruster dynamic behavior can be very important and influence overall system behavior in a manner fundamentally different from most hydrodynamic and inertial nonlinearities. The dynamics of the thruster dominate behavior of the vehicle by restricting the maximum closed-loop bandwidth and creating a limit cycle [9].

The propeller is mounted in a duct or shroud which increases the static and dynamic efficiency of the thruster. The velocity of the fluid entering the thruster shroud effectively changes the angle of attack of the propeller, thus altering the force produced. Cross-flow effects are much more difficult to model and have been shown experimentally to be highly dependent on the position of the thrusters on the vehicle. In both cases, the reduced amount of force produced by the thruster will reduce the overall gain of a control system unless these effects are specifically included in the controller design. The steady-state relationship between torque and thrust is nearly linear, while the steady-state relationship between propeller speed and thrust is nonlinear.

## 8. CONCLUSION

In this study case can conclude the major problem identification will be discussed details such control system coupling, under actuated condition, pose recovery and communication technique. The detail study of problem statement will be one of

the contributions on research for unmanned underwater vehicles especially ROV. The researchers can study to design the good controller so that control system of ROV will be the good and excellent performances. Researchers also can come out with a new design of cable for ROV especially a smaller size or a suitable material for isolation with neutrally buoyancy. The ROV design should be able maintain a certain path or depth following mission under actuated condition when one or more of thrusters malfunction. The researchers can design the ROV with recovery or home-keeping or platform station with environmental disturbances present such as wind, waves and current and unexpected environmental disturbances. Acoustic signal that low in frequency is used for ROV Communication to send a data to control panel. Hope with present this paper will be helpful for new research can be studied for another researcher to improve the performances of ROV.

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