Design and Development of a Remotely Operated Underwater Vehicle

A Thesis Submitted
In Partial Fulfilment of the Requirements
for the Degree of
Bachelor of Technology

by

Durgansh Mishra (190103036)
Khairnar Sanket Narendra (190103050)
Monika Poonia (190103059)

to the

DEPARTMENT OF MECHANICAL ENGINEERING
INDIAN INSTITUTE OF TECHNOLOGY GUWAHATI

November 2021

CERTIFICATE

It is certified that the work contained in the thesis entitled "***Design and Development of a Remotely Operated Underwater Vehicle***", by "*Mr.Durgansh Mishra*", "*Mr.Khairnar Sanket Narendra*", and "*Ms. Monika Poonia*", has been carried out under my supervision and that this work has not been submitted elsewhere for a degree.

Dr. Biranchi Panda

November, 2021.

Department of Mechanical Engineering,

I.I.T. Guwahati

Declaration

I declare that this written submission represents my ideas in my own words and where others' ideas or words have been included, I have adequately cited and referenced the original sources. I also declare that I have adhered to all principles of academic honesty and integrity and have not misrepresented or fabricated or falsified any idea/data/fact/source in my submission. I understand that any violation of the above will be cause for disciplinary action by the Institute and can also evoke penal action from the sources which have thus not been properly cited or from whom proper permission has not been taken when needed.

Khairnar Sanket Narendra	Monika Poonia	Durgansh Mishra
190103050	190103059	190103036

Department of Mechanical Engineering,

I.I.T. Guwahati, Assam, India

Dedicated to

our Parents, Friends and Teachers

Acknowledgment

We would sincerely like to express our gratitude towards our supervisor, Dr. Biranchi Panda, for giving us the opportunity to work on this wonderful project. We also thank him for guiding us throughout the course of this project. Right from introducing us to ROVs to constantly motivating us to learn new things about it and working on some new ideas to implement on our project, he has been a great mentor and we will forever be indebted to him for this. We would also like to thank Mr. Avilash Sahoo for his useful insights on the ROV which we are currently working on.

Durgansh Mishra
Khairnar Sanket Narendra
Monika Poonia
IIT Guwahati
November, 2021

Contents

Nomenclature

ROV	Remotely Operated Underwater Vehicle
AUV	Autonomous Underwater Vehicle
CG	Centre of Gravity
DoF	Degree of Freedom
$3D$	3 Dimensional
RGB	Red green blue
HDR	High dynamic range
PSF	Point Spread Function

Chapter 1

Introduction

1.1 Why ROVs?

Almost three-fourths of the Earth's surface is covered with oceans, rivers, and water bodies which inhabit a large variety of flora and fauna. Most of it remains unexplored to date. Studying these underwater ecosystems is crucial for humankind today. Sending humans and manned vehicles underwater is dangerous, less economically viable, and has its limitations. ROVs and AUVs have provided us with a better alternative. They are safe, cheaper, can go deeper, and reach less accessible places.

ROVs are remotely operated underwater vehicles that are controlled by a crew either offshore or aboard a ship. ROVs are highly maneuverable. A tether is used to control the vehicle, receive information from onboard systems, and supply power. These underwater robots are extensively used for scientific research, military purposes, and broadcasting aquatic environments. They use various sensors, cameras, etc., to collect data and take pictures. Underwater images play a crucial role in ocean exploration. Still, they often suffer from severe quality degradation due to light scattering by particles, and light absorption causes color attenuation in water medium.

1.2 Redesigning an ROV

In this project, we will review methods for improving a previously built ROV. We have thought of making modifications to the hull shape, optimizing the distance and position of thrusters, adding image processing tools to our existing model, and adding a mechanical arm to it.

This paper will review existing literature on ROVs, mechanical arms, image processing, controlling, etc. We will then discuss the problems found in the existing model and identify their solutions based on the current literature. We will also analyze existing literature and perform simulations for the new additions planned for the ROV.

1.3 Image Processing

Underwater images play a key role in ocean exploration but often suffer from severe quality degradation due to light scattering by particles, and light absorption causes the color attenuation in water medium. Although major breakthroughs have been made recently in the general area of image enhancement and restoration, the applicability of new methods for improving the quality of underwater images has not specifically been captured. In this paper, we review the current research development of underwater image processing and classify the approaches into two categories: image restoration and image enhancement. We also review different algorithms and methods, to give clearer ideas on the techniques present in the underwater image processing.

1.4 Objectives

- Optimizing stability and minimizing drag for the current model
- Finding the optimal position and specifications for the thrusters.
- Adding camera, lights, and other required sensors.
- Optimizing Image processing
- Checking feasibility of different hull designs as per the requirements
- Addition of Mechanical arm and sample collection box
- Frame structure to mount all the components and provide a platform for the multiple hull design

- Work on rotatable thrusters
- Changing the Arduino based mechanism with Raspberry PI
- Testing of the final model in a lake

Our initial plan is to work on the above objectives on the model we are currently working on. If we cannot achieve these objectives on that model, we will start working on an entirely new model while keeping in mind the initial goals that we set as well as the problems that this model was facing.

1.5 Organization of paper

The report is organized as follows;

Chapter 2 discusses Literature survey related to ROVs, Image processing, Thrusters.

Chapter 3 presents the methodology of redesiging an ROV.

Chapter 4 concludes our report and discusses future work.

Chapter 2

Literature Review

2.1 Design

Since early ages, humans have been settling around rivers and water bodies to utilize their resources. They play an essential part in the development of humankind. ROVs can be an excellent tool to explore these underwater environments and collect data such as temperature, pressure, the composition of water, depths, etc. It can capture images to analyze flora and fauna, collect riverbed samples, do 3D mapping, study water pollution.

The design of ROV is a significant factor affecting its performance. The design aspects that affect ROV's performance are its shape, center of buoyancy and center of mass, position of thrusters, diameter of tether. While designing an ROV, one should keep in mind that the design should be such that its drag is minimum, enough space for onboard systems is present, its water-tight, and easy to manufacture, assemble and disassemble. If the ROV is neutrally buoyant, we can save a great deal of power. The thrusters should be kept such that the ROV can be lifted without any tilt or torque.

On the basis of its shape, the ROVs can be broadly classified into two categories:

- Non-torpedo-shaped
  - Less drag and faster speed
  - Useful for longer range and at low to moderate currents
  - Suitable for low-resolution surveys of larger areas

  - Hard to maneuver precisely over small areas
  - Need translational speed for complete control of the vehicle
  - Generally, have 6 DoF, namely x-y-z translation, roll, pitch, and yaw. (Current model has 4 DoF)

- Torpedo-shaped
  - More drag and less speed compared to torpedo-shaped design. Higher drags make them challenging to use in significant currents.
  - Useful for short-range, high-resolution surveys.
  - Better suited for optical and bathymetric surveys.
  - It can be controlled more precisely in lower speeds and shorter ranges.
  - The multiple hull design is more stable in pitch and roll.

Our previous model is torpedo-shaped, so initially, we will also be working with a torpedo-shaped model. In most cases, a non-torpedo-shaped design is adapted for mechanical arm addition. The use of external frames can provide an additional base to mount various sensors, cameras, lights, thrusters, etc. They can also be used to attach the hull(s), which houses all the electronic parts of the ROV. The hull contains the onboard computer, housing for sensors, wirings, deadweights, batteries, and sometimes even the camera, among other things. This is due to why the hull should always be water-tight.

Most commercially used ROVs or the ROVs used for scientific research use a mechanical arm and a sample collection box. The mechanical arm is a robotic arm that is remotely controlled and is used by the ROV to perform operations underwater. These operations generally comprise taking samples from the riverbed, and the sample collection box is used to store the sample. The mechanical arm is more suited when at the bottom of ROV, as seen in most commercially available ROVs like the Girona 500 or Triton concept. This way, the CG is as down as possible, and the arm can easily access everything from the bottom as most of the sample collection work is generally done from the riverbed itself. The challenge here will be controlling the arm and making sure the ROV's motion is not hindered or imbalanced due to the movement of the arm.

As we plan to capture images and do image processing to get high-resolution data, a critical factor will be the camera and its positioning. While going through the literature present, we have analyzed that the best position for the camera is at the front of the ROV for a horizontal torpedo-shaped design.

While designing an ROV, we need to keep it in mind to minimize the drag in all ways possible. This will help us navigate better, reach more considerable depths, and carry out our tasks easily. The design of the hull needs to be streamlined to minimize drag; the previous design lacks this as its top portion is flat-ended, much different from its initially proposed design, which can lead to increased drag.

The thrusters aid the ROV with its movement. Their positioning, orientation, number, and distance from the hull significantly determine the vehicle's performance. Their positions need to be optimally chosen to strike a balance between maximum power and better control. Even a slight mishap in the thruster position can lead to unbalanced torque and thus to instability in the vehicle.

2.2 Image Processing

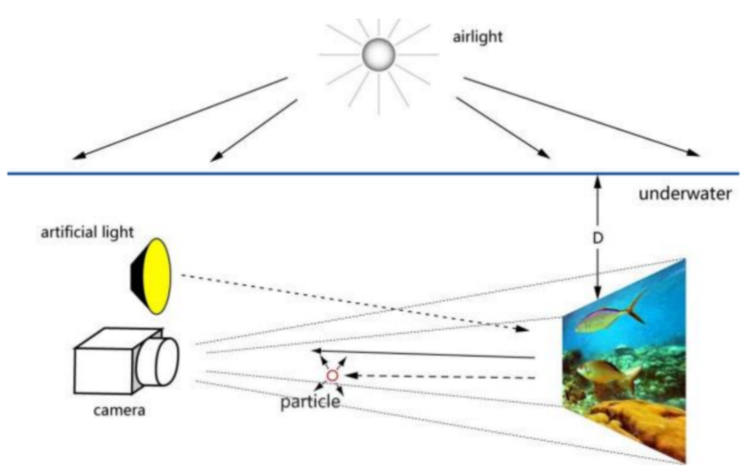

Figure 1. Underwater Imaging System.

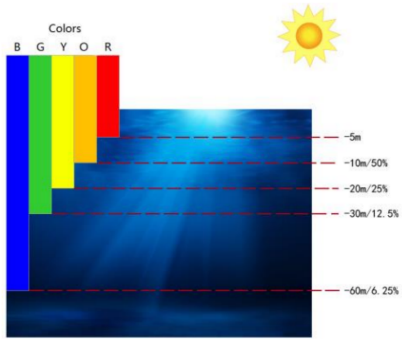

Figure 2. Schematic of Light Absorption.

The underwater imaging system is shown in Figure 1. Images captured by the system have two features:

1) Low visibility and blur of image caused by light attenuation: Light radiation exponentially decays in air, fog and water, which limits the distance of visibility with the range of 20 meters in clear water and fewer than 5 meters in muddy water. The decay of light radiation is caused by absorption (decrease of luminous energy) and scattering (change of light path direction) in water.

2) Color fading caused by light absorption: The absorption of light by water shows its selective feature for different areas of light spectrum, as shown in Figure 2. The density of water is 800 times of that of air. The energy of light decrease with the increase of the depth of water

2.2.1 Underwater Image Restoration Algorithms

Underwater image restoration algorithms can be roughly divided into algorithms based on physical models and blind restoration. Physical restoration models through a calculated model parameters to solve the model. Blind restoration models is used to recover the image from the observed image without using priori information of degradation process.

On the basis of Jaffe-McGlamery underwater imaging model, Trucco proposes a simplified version of filter to automatically adjust the image restoration. The optimal value of filter parameters automatically by measuring standards of the global contrast to estimation image quality. A simplified model can get more ideal result based on limited backscatter.

Yang use low-complexity of image enhancement method based on dark channel prior. In the process of scene reconstruction, the median filter is used to estimate the transformation function of the input image, and use dark channel prior to calculate the atmospheric light. At the same time, the underwater images whole slant blue, G and R channel image enhancement makes image overall balance. Lu calculate light attenuation and scattering parameters under specific water depth is also used the dark channel prior, to use oriented triangle bilateral filter to remove the fuzzy and speed up the calculation, then used Automatic Color Equalization to enhance image information. This method combines the restoration method and enhancement method.

2.2.2 Underwater Image Enhancement Algorithms

Original underwater image is directly enhanced in partly or as a whole to contain rich information and become easy to be recognized and processed. Existing underwater image enhancement algorithms can be divided into four categories:

1. Algorithms Based on Contrast Ratio and Histogram:

Traditional methods like contrast stretching, histogram equalization and adaptive histogram equalization with contrast ratio constraints can still reach good results.

2. Algorithms Based on Retinex Model:

The objective of computational model based on Retinex theory is to eliminate the impact of scene illumination component and get actual reflected component. Retinex is a model describing color in-variance.

3. Algorithms Based on Filtering and Other Signal Processing Methods:

Filtering methods with high performance in noise reduction can also be widely applied to underwater image enhancement, such as adaptive filtering, wavelet transform, homomorphic filtering, bilateral filtering, etc.

4. Algorithms Based on Comprehensive Methods:

There are algorithms combining image restoration and enhancement methods that shows higher performance on resolving noise, low contrast ratio, non-uniform illumination, blurred image, etc. than single algorithm.

Chapter 3

Methodology

We will adopt the following approach for our project:

- Literature review
- Identifying problems with the existing model:
  - Drag and stability:

    Due to vertical hull design the ROV experiences higher drag than conventional horizontal hull design while surging. We will have to test the stability in both orientations.
  - Position of thrusters:

    The thrusters are positioned closer to the hull than the CAD model, effect of which will have to be looked into.
  - Camera Position:

    With the current vertical orientation of the ROV, it is not feasible to add a camera as the thrusters block the view. Placing the camera at the bottom of the hull is not possible in the current design.
  - Upper end of the hull is flat which is different from the proposed model. It increases the drag while heaving as well as while surging.
- Using literature review to theorize possible solutions
  - To decrease the drag, one solutions can be to change the axis of our ROV after it submerges fully in the water to its desired depth. The horizontal

orientation will be better suited for camera positioning and taking images. Problems with this idea is that we will have to consider the buoyant forces in both directions and have to make necessary changes.

  - Second option is to make the ROV horizontally oriented.
  - Hemispherical part needs to be added to the upper end to make the design more suitable for motion in water.

- Adopting a theoretical approach to solve them
- Testing the theoretically feasible methods practically
- Adopting the viable solutions to our ROV
- Work on the additions like the mechanical arm, sample box, etc.

  - Frame Structure:

    External frame structure can provide a platform for mounting additional features like sensors, camera, thrusters, mechanical arm. It also guards the hull from various obstacles. It can also increase stability. On the downside, it increases the weight and also the drag. More research and analysis needs to be done.

  - Mechanical Arm and Sample Collection Box:

    Current design is not suitable for an addition of a mechanical arm. There should be an outer structure (like an external frame) to hold the sample box and the arm. The ROV should be able to compensate the disturbance caused by the movement of the arm.

  - Multiple Hull Design:

    Multiple hull design is suitable for mechanical arm addition. It's more stable and easy to maneuver.

  - Rotatable Thrusters:

    Thrusters can change their orientation according to the direction of motion. This way we can minimise the number of thrusters or increase the thrust. But we will have to check its feasibility

- We are checking if they can be added to the previous design. Otherwise, work on a new design, keeping in mind all the new design additions from the start.
- Make an ROV from scratch according to the proposed design
- Keep working to improve its efficiency, controlling, and onboard systems. We can finally think of converting it into an AUV as well.

Chapter 4

Work plan for upcoming semesters

As we move forward, we have planned to do the following:

5th Sem: Literature review and making our objectives clear. Proposing a tentative change in design and deciding on how to approach it

6th Sem: We will perform simulations to the existing design and make initial changes to it to test if we can work on the existing model or if we will have to work on a completely new one.

7th Sem: (*If we work on the old model*) Complete work on all the problems identified with the old model and perform simulations for design additions.

(*If we work on a new model*) Start making a new model, keeping in mind all the problems that the previous model faced.

8th Sem: Complete work on the design additions; as we complete it, we will finally make the ROV autonomous.

References

1. Vikrant P. Shah, “Design Considerations for Engineering Autonomous Underwater Vehicles”, The University of Texas at Austin, 2005

2. Avilash Sahoo et al, “Design of a Compact ROV for River Exploration”, IIT Guwahati, 2017

3. J. Singh, D. Gandhi, M. Sanghani, P. S. Robi and S. K. Dwivedy, “Design and development of underwater robot,” 2015 International Conference on Robotics, Automation, Control and Embedded Systems (RACE), 2015

4. P. Ridao et al, “Intervention AUVs: The next challenge”, Annual Reviews in Control, 2015

5. Avilash Sahoo et al, “Advancements in the field of autonomous underwater vehicle”, IIT Guwahati, 2019

6. Harry Bohm, Steven W. Moore, and Vickie Jensen “Underwater Robotics – Science Design and Fabrication”

7. Jebelli A, Yagoub C and Dhillon S, “Design and Implementation of an Autonomous Underwater Vehicle (AUV) with PTFE”, University of Ottawa, Ottawa, Canada

8. Open ROV forum, https://forum.openrov.com/

9. SOI’s ROV, youtube.com/playlist?list=PLJGVqQI3okzaOH4YqKxp3p3RB7PALgqCU

10. Trucco E, Olmos-Antillon A T, ”Self-tuning underwater image restoration”, IEEE Journal of Oceanic Engineering, 2006

11. Yang H Y, Chen P Y, Huang C C, et al, ”Low complexity underwater image enhancement based on dark channel prior”, Innovations in Bio-inspired Computing and Applications (IBICA), 2011

12. Lu H, Li Y, Serikawa S, ”Underwater image enhancement using guided trigonometric bilateral filter and fast automatic color correction”, Proc of 20th IEEE international conference on image processing, 2013

13. B. McGlamery, “A computer model for underwater camera system,” Ocean Optics VI, S. Q. Duntley, Ed., vol. 208 of Proceedings of SPIE, 1979.

14. rovmaker.com/en/2021/05/11/horus-realtime-underwater-image-processing/