Spring Term Report - VT24

Mechatronics, Advanced Course
MF2058

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May 20, 2024

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1 Introduction

The following section gives an introduction to the project. It includes the background to the project, project description, goals of the project, a proposed scenario with requirements and finally, the project's organizational structure.

1.1 Background

Underwater archaeology has become an increasingly popular discipline in the past two decades due to both commercial and industrial interests in exploiting and preserving the seabed [1]. The exploration and investigation of underwater sites, however, presents an array of challenges. Sites are often situated deep underwater and can be inaccessible and dangerous for human divers due to high pressures, cold temperatures and strong currents, to name a few [2]. Technological advancements have allowed underwater archaeologists to overcome some of these obstacles by utilizing underwater vehicles such as Remotely Operated Vehicles (ROVs) and Autonomous Underwater Vehicles (AUVs) for deep-sea archaeological missions.

The project explores the possibilities of the BlueROV2, an affordable and widely-used ROV, to be implemented as an AUV in order to navigate autonomously around an underwater site while simultaneously deploying underwater payloads and capturing images of the site for three-dimensional (3D) mapping. Currently, the BlueROV2 has path-following capabilities using PID control. This control algorithm, however, lacks precision and robustness so the implementation of Model Predictive Control (MPC) is explored since it has showcased promising results for autonomous applications.

1.2 Project description

The nine month long project is conducted at KTH Royal Institute of Technology and is a part of the *Mechatronics Advanced Course*. The project's stakeholder is SAAB underwater systems, who requested MPC to be implemented on a BlueROV2 combined with image enhancement, 3D-reconstruction of underwater sites, an information model of the entire system and a robotic arm. The former request has been revised to instead include an underwater payload deployment system. A collaboration has also been started together with the Swedish Maritime Research Centre (SMaRC) at KTH which will provide the project with their both digital and physical resources and work.

1.3 Goals

- Create a block diagram to model the information flow between subsystems
- Produce a functioning simulation environment for the testing and validation of the BlueROV2
- Implement an MPC with 4 degrees of freedom to control the BlueROV2
- Create an image enhancement algorithm to enhance the images captured by the BlueROV2's on-board camera
- Implement an image reconstruction algorithm to generate a 3D-model from the enhanced images
- Design and construct a system for the deployment of underwater payloads

1.4 Delimitations

Due to the sheer size and complexity of the project's constituent parts, several delimitations had to be made as presented below.

- The BlueROV will limited to four degrees of freedom for the MPC. It will only be movable along the x,y, and z-axes and rotatable around the z-axis.
- Perform 3D-reconstruction on top-side computer as a computation capacity constraint
- The MPC will be developed in a pool environment

1.5 Scenario

In order to define and limit the scope of the problem and incorporate all the stakeholder's requested functionalities, a hypothetical scenario was made up, pictured in Figure 1.1. The scenario will be re-enacted during testing and when showcasing the project during the demonstration.

In this scenario, the BlueROV2 should be able to navigate between three pre-determined waypoints, using MPC, where interesting objects are located. When the BlueROV2 reaches one of these waypoints, it should deploy an Underwater Locator Beacon (ULB) close to the interesting object and capture images of it for enhancement and later 3D-reconstruction. This will provide information about what object is on the seabed and the ULB will make it possible for another underwater vehicle to revisit the site. The actual functionalities of the ULB, however, will not be used since this exceeds the scope of this project.

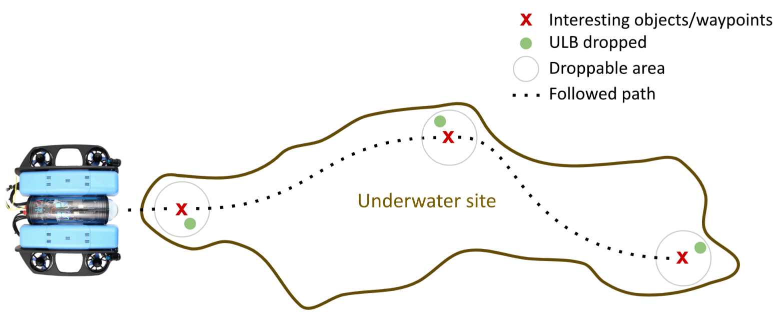


Figure 1.1: Scenario overview

1.6 Requirements

This section outlines the preliminary requirements that have been set for the underwater payload deployment system based on extensive research and discussions with the stakeholders and our coach. The requirements for the remaining parts have not yet been extensively defined. These requirements are subject to change as the knowledge and development of each subsystem progresses throughout the fall semester. At the moment there are no hard requirements for any other subsystem than the deployment system. As per common practice in requirement writing, the use of the word "shall" specifies a strict requirement that has the highest priority whereas "should" indicates a requirement of second priority.

Deployment System

The following requirements have been established for the ULB release mechanism.

- The mechanism shall be mounted within the enclosed volume of the BlueROV2
- The mechanism shall be able to handle ULBs that are 33 mm in diameter and 100 mm in length and that have a maximum weight of 200g

- The ULB magazine shall be able to store three ULBs at once
- The total weight of the system, when the magazine is fully loaded, shall not exceed 2000g.
- The electrical enclosure shall be waterproof with an IPx8 rating
- There shall be no interference between the mechanism and other components of the BlueROV2
  - The mechanism should not obstruct thruster flow
  - The mechanism should be placed as close to the BlueROV2's center of mass as possible
- The design should be simple to construct and integrate
  - The mechanism should not consist of more than ten unique components
  - The design of the mechanism should allow for modularity, i.e. b able to be independently mounted without any structural changes to the platform.
- The mechanism should be able to release ULBs at an interval of maximum 10 seconds

1.7 Project Organization

In its current configuration, the team consists of eight team members. In order to have efficient work flow and a centralized storage of files, Microsoft OneDrive is used. For communication within the team, a communication platform called Slack is used. On the platform, several communication channels were created for different project topics (general, meetings, MPC, computer vision etc.) to keep conversations organized and make it easy to revisit relevant information. A contact person was appointed for communication with the stakeholder and any other relevant parties. Bi-weekly meetings were scheduled with the stakeholder throughout the spring semester and weekly reports were composed to provide an overview of the project status to the stakeholder.

In terms of work organization, the project can be divided into five areas: simulation, MPC, computer vision, underwater payload deployment system, computer vision and system integration. Team members will work on these areas in subgroups of two with scheduled rotation. The plan is to rotate one step at a time, so that each team member spends two rotations at a time working in one area. This overlap ensures that one team member can transfer the knowledge obtained in the previous cycle on to the next one. This rotation of responsibilities allows for maximum knowledge to be gained, and each team member offers their unique perspective for each area.

In order to be minimize and be well prepared for risks within the project, a risk analysis was made, seen in figure A.1. The evaluated risks were mostly technical and gives us a broad reasoning to help us prevent these risk from happening.

During the fall term, the second part of the course starts. In figure B.1 a preliminary plan of this period can be seen which outlines our plan of action.

2 State of the Art

This section presents the state-of-the-art methods and solutions of the different parts of the project as well as any relevant technical and contextual information.

2.1 Underwater Archaeology

Underwater archaeology is a branch of archaeology focusing on the exploration and uncovering of submerged artifacts and sites. Its significance lies in its contribution to our understanding of world prehistory, human development, and dispersal [1]. The exploration of underwater realms offers unique insights into these areas of study.

2.1.1 Methodologies

There is a wide range of methodologies used within underwater archaeology. The variation is a cause of the complexity that underwater archaeology missions bring. If the purpose is to analyze an archaeological site, terrestrial methodologies can be used, albeit only limited to shallow waters due to the dangers of deep waters for divers [2].

In this case underwater vehicles can be used. The utility of these vehicles are depending on the visibility in the sea and depth, but also factors such as the underwater terrain and environment. Some common methodologies used to find underwater archaeological sites are as follows:

Acoustic Methods

When searching shallow waters or exposed areas, acoustic mapping can be used. Examples of technologies utilized for this are side-scan sonars and multibeam echosounders which both can provide detailed acoustic maps of the sea bed in the scanned area [1]. Advantages of these methods are that large areas can be scanned relatively fast with precision ranging from centimeters to meters. These methodologies are especially useful in areas with low visibility.

Magnetic and Electromagnetic Methods

If the case is that the archaeological site has a magnetic imprint, magnetic and electromagnetic methodologies can be used. These methodologies are especially useful when the site cannot be detected with acoustic methods [1]. The level of detail provided by these methodologies decreases rapidly with the distance to the sensor. Therefore it is important that the sensors are towed close to the seabed.

Photogrammetry

Photographic techniques are used to store image data of the archaeological site and also create an accurate 3-dimensional model of it.

One main drawback with this methodology is that an the seafloor needs to be exposed and they do not provide precise dimensional information of the underwater archaeological sites [1]. This is though possible with underwater laser scanning (USL), that can provide high-detailed 3-dimensional models with millimeter precision. USL can be utilized by ROVs, AUVs or divers. For further information about 3D image reconstruction, see section 2.5.2.

2.1.2 Challenges

There are a multitude of challenges that arise in underwater archaeology, specifically ones that are not prevalent in the discipline's terrestrial counterpart. Seemingly trivial land archaeology tasks become very difficult to execute underwater due to, but not limited to, difficult communication between divers, psychological factors such as anxiety and fear, and a significant reduction in dexterity [2]. As a result, underwater archaeological tasks performed by humans can be dangerous and very time-consuming, let alone impossible in some circumstances.

Therefore, it is preferable to utilize UUVs such as ROVs and AUVs in order to reduce or even eliminate the number of divers and diving hours required for conducting underwater archaeological tasks. One of the major technological challenges in underwater archaeology, however, is the wide variety encountered of scale and environment, since both affect the technique or methodology used [1]. For instance, the seabed can be sandy or rocky with varying hardness of sediment, placement of artifacts etc. [1].

2.2 Autonomous Underwater Vehicles

Autonomous underwater vehicles, also known as AUVs, are a type of unmanned vehicle. Unlike remotely operated vehicles (ROVs) and unmanned underwater vehicles (UUVs) in general the AUV is entirely autonomous and does not receive any type of transmitted data through a tether, like an ROV, or through sound waves. This means that the AUV must rely solely on its on-board sensors to provide it with the information necessary for its mission, while also operating underwater, rendering some of the most useful sensors, like GPS, unusable.

These limitations usually mean that the AUVs must be equipped with extra, often costly, sensors as well as with advanced software and the processing power to back it up. This increase in sensors, software and hardware is used to mitigate the loss of information that something like a tether would have provided, but is usually not enough to bridge the entire gap and it is not uncommon for AUVs to have to surface in order to improve their current state estimations. [3] [4]

2.3 BlueROV2

The BlueROV2, pictured in Figure 2.1, is a popular, affordable and high-performing ROV for underwater exploration with the base version being equipped with a six-thruster vectored configuration and open-source electronics and software [5].

Figure 2.1: BlueROV2 with 8-thruster setup

The ROV has a maximum operating speed of three knots and it is therefore recommended to operate it in a maximum water current of 1-1.5 knots. It has an available buoyancy of between 1.2-1.4 kilograms and with maximum gain, the produced thrust is around seven kilograms. [5]

2.3.1 Hardware

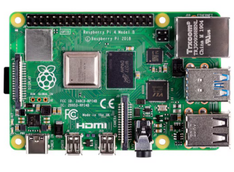
The frame of the ROV can be extended in order to attach larger payloads and there is a possibility to choose between a six and eight thruster setup. The ROV can be configured with either acrylic or aluminium enclosures, resulting in a depth rating of 100 and 300 meters respectively. It is currently controlled by a pilot on the surface using a gamepad controller, a laptop and the QGroundControl user interface. The pilot is connected to the BlueROV2 via a tether, currently available in lengths from 25 to 300 meters of depth.[5]

The thrust-to-weight ratio is high due to patented T200 thrusters and the vectored configuration ensures that the ROV can move in all degrees of freedom.

Mounted in the front of the ROV is a wide-angle low-light camera that can be tilted up and down and it is possible to configure two or four dimmable LED lights to increase visibility [5].

2.3.2 Processors and Controllers

The processing and computing is conducted on a Raspberry Pi 4 computer that runs the open-source BlueOS software, as shown in Figure 2.2 (a) [5]. Raspberry Pi 4 has a number of different RAM capacities from 1 GB up to 8 GB and comes with gigabit Ethernet, wireless networking and Bluetooth. It also comes with a total of four USB ports, of which there are two USB2 and two USB3 ports. In addition, it has two HDMI ports supporting 4K displays.[6] The Raspberry Pi is connected to the Navigator Flight Controller, shown in Figure 2.2(b), that loads the ArduSub autopilot firmware, which processes the pilot input and sensor data. It also controls the vehicle's motors, lights, sensors and relays.[7]



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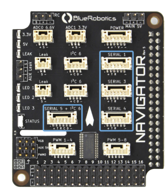


(b)

Figure 2.2: (a) Raspberry Pi 4 (b) Navigator Flight Controller

2.3.3 Sensors

To determine the BlueROV2's orientation, an Inertial Measurement Unit (IMU), magnetic compass and gyroscope are embedded in the Navigator Flight Controller [7]. In order to facilitate for advanced capabilities such as autonomous exploration and position holding, there is an option of adding a Doppler Velocity Log (DVL) [5]. A DVL measures the velocity relative to the ocean floor using acoustic transducers that send and receive pulses. [8] Except for providing an accurate velocity measurement of the BlueROV2, it also gives detailed *relative* positioning, however in order to get the BlueROV2's *global* position, a Ultra-Short Baseline acoustic positioning system (USBL) or a Global Positioning System (GPS) needs to be added.[8] The sensor array can be combined using a kalmanfilter for a full state estimation.

2.3.4 Software

BlueROV2 is controlled by BlueOS. The BlueOS software manages the camera and tether connections and runs the ArduSub vehicle control software. It is easy to update and add new features using BlueOS and it is a growing project that continuously provides new features for the BlueROV2 platform.[5]

2.4 Model Predictive Control

To understand MPC, one first has to understand the concept of an optimization based control strategy like Linear Quadratic Control (LQR). LQR is based around a cost function which is used to optimize the control parameters in a full state feedback system like the one in Figure 2.3. One reason for using LQR instead of regular pole placement for a full state feedback system is that it is more intuitive to tune.[9] The MPC control loop as in Figure 2.3 uses the reference states along with the state estimator as inputs to the optimizer to calculate the best control inputs $U(k)$ to follow the Reference $Ref(k)$.

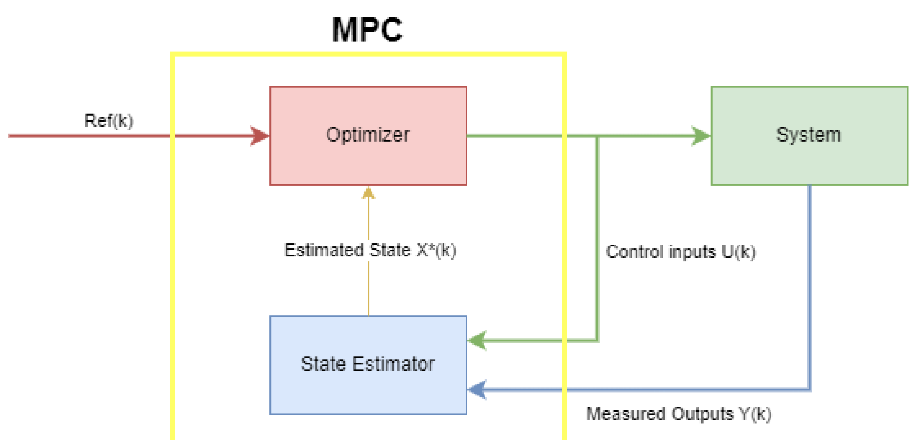


Figure 2.3: Simple model of a full state feedback control system

For LQR, the cost function that you set up is usually based on the entire time horizon and the problem is optimized once, leaving you with a solution that gives you the optimal system parameters for the whole time horizon. For MPC however, the cost function is not based on the entire time horizon, instead it is based on a receding time horizon where the optimization takes place onboard as seen in equation 2.1 where N is the receding time horizon. This is done at every time step which makes the MPC very computationally heavy.

$$J = \sum_{k=0}^{N-1} \left(x_k^T Q x_k + u_k^T R u_k \right) \tag{2.1}$$

Because of the receding time horizon approach, MPC may compute a suboptimal result for the entire time horizon as compared to LQR. This suboptimal result, however, would be based on linearizations around the operating point that also take place onboard as compared to LQR where only one linearization is used. This is one of the main drawbacks with LQR where it may become unstable if operated too far from the modeled linearized point.[10]

2.4.1 Challenges and Limitations

MPC might seem as the optimal control strategy for all implementations given the nature of the calculations resulting in an optimal strategy. The major issue is the time it takes for the optimizer to calculate the optimal control variables which is why it is more often used in slower processes e.g the petroleum industries where the MPC will work on a much larger time-scale as compared to an embedded control system on a ROV [11].

Like a state feedback controller, there is always a challenge in measuring or modeling all the states. In situations where obtaining up-to-date measurements or any measurements at all is not feasible, it may be necessary to introduce a Kalman filter to estimate the unknown states.

Although modern solutions exist for designing an MPC controller like MATLAB, there is still a requirement for a comprehensive understanding of the model and system from the control designer to choose the cost matrices to actually find the optimal control. Likewise, any MPC controller is only as good as the model it is designed from and the steps along the way such as linearization and testing of the model.

2.4.2 Previous Implementations

Multiple implementations of MPC have been performed on underwater ROVs in an attempt to make them autonomous. One example of this is Naeem, Sutton and Ahmads work [12] that implemented an MPC on a pure pursuit guidance system to follow an underwater pipeline. They used a genetic algorithm using Darwin's theory on genetics to calculate the optimal control inputs using the MPC cost function.

Another attempt utilizing the BlueROV2 has been made by Einarsson and Lipenitis at Aalborg University [13] where they implemented an MPC to control the BlueROV2. They found that the Pixhawk 4 and the Raspberry Pi 3, which acted as the brain for their BlueROV2 proved hard to work with. This led to them changing out these components to more user-friendly hardware to use for their implementation. They also came to the conclusion that a DVL is a useful addition to the sensor setup.

2.5 Computer Vision

Another essential part for this project is computer vision. It is a rapidly growing field with a lot of state-of-the-art technologies and applications, largely due to the advances within artificial intelligence. During this project, the two categories of computer vision that will be utilized are 2D image enhancement and 3D image reconstruction.

2.5.1 2D Image Enhancement

For underwater robot exploration using a camera, a common problem is the given poor image quality. This is mainly due to light absorption and scattering. The light absorption occurs because of the different wavelengths in light. As visualized by Figure 2.4, the light is gradually absorbed corresponding to its wavelength, red light being the longest wavelength and blue being the shortest. That is the reason why blue and green are more dominant in underwater images. [14]

Additionally to this, scattering is another phenomenon that worsens the quality of underwater images. It is a phenomenon where underwater particles are reflected into the camera and creates blur and poor vision within the image. This is also visualised in Figure 2.4. Therefore, the purpose of image enhancement is to generate a better quality image of a given image by de-noising and color-correcting for improved visibility. [14]

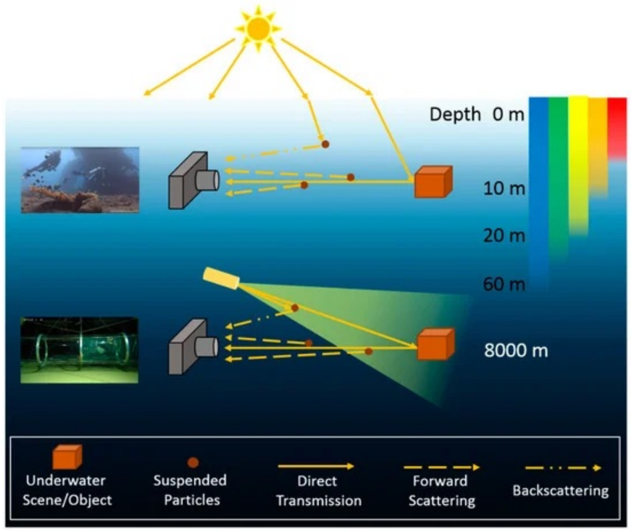


Figure 2.4: Underwater light absorption and scattering

This can be done in many ways. To begin with, there exists physics-based methods to solve this. However, while this physical process is well described theoretically, the model depends on many parameters such as water characteristics, depth and structure of the scene. These factors make recovery of these parameters difficult without simplifying assumptions or field calibration; hence, restoration of underwater images is a non-trivial problem. [15]

However by using deep learning and only utilizing a camera, this problem can be solved to work in different water settings and without needing to purchase additional sensors. Deep learning for image enhancement is a state-of-the-art field and it exists different methods to approach it. The most common methods for this is what's called synthesizes, where something new is generated from the input. Within synthesizes, the three most common types are Generative Adversarial Networks (GAN), autoencoders, and diffusion models. All three of these can be used for image enhancement. Their broad advantages and disadvantages can be visualised by Figure 2.5. [16] As the aim of this project is for the image enhancement to run real-time on the onboard-computer, fast sampling is needed while giving high quality samples. Therefore GAN is a common choice for image enhancement for underwater robots [17].

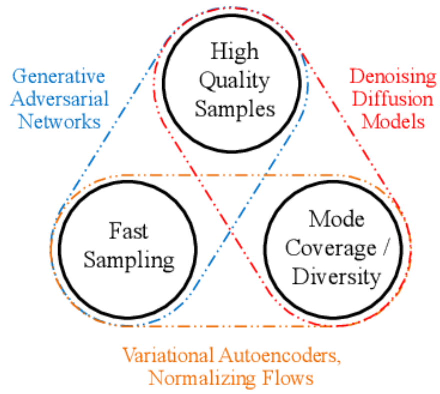


Figure 2.5: The generative learning trilemma

However, a disadvantage with GANs is the mode coverage, meaning its ability to adapt in new environments. To solve this, Zhisheng Xiao et al. has developed a combined method with GAN and diffusion model claimed to solve the generative learning trilemma. [16] Conclusively, using deep learning for underwater image enhancement is state-of-the-art within this field and can help with further underwater operations needing clear vision.

2.5.2 3D Image Reconstruction

In underwater archaeology, a central part is the mapping of the sites. The harsh underwater environment combined with bad visibility makes mapping very difficult. In this project the main application of the computer vision is to map and get a clear view of a site on the ocean floor using the BlueROV2 on-board camera. 3D image reconstruction is a complex subject that can be solved in multiple ways, traditionally by matching points from the different images. A lot of research has gone into reconstruction of smaller indoor scenes and less into large scenes with worse conditions [18].

There are two main methods, structure from motion (SfM) and multi-view stereo (MVS). SfM is a photogrammetry method that uses a series of images from different viewpoints and reconstructs a 3D structure from the projections. MVS uses a set of images of known positions and viewpoints to infer the 3D geometry of an object[18].

The advancements in deep learning have come with great improvement for 3D reconstruction from a single 2D camera without the need for prepossessing to specify angles and distances to the object. These methods train Neural Radiance Fields to find the point cloud representation of the object from unstructured images.[19].

2.6 Underwater Locator Beacons

A common type of payload that can be deployed either manually or with the use of an ROV or AUV is an Underwater Locator Beacon (ULB). A ULB is an acoustic transducer whose purpose is to emit acoustic signals. The intention of the ULB is to provide or generate a position that later can be detected. For detection of it, methods using directional hydrophones or sonar systems can be used [20]. Since underwater communication differs from aerial communication, it makes multiple of the communication alternatives for air invalid due to the differences in the two mediums [21]. For maritime communication, acoustic transducers are therefore mainly used due its abilities to overcome the complexities of the environment. The most common transducers are either piezoelectric acoustic transducers or electromagnetic acoustic transducers. [21].

3 Concept Design

3.1 Information modelling

To implement the information modelling, a block diagram in MATLAB Simulink of the information flow of the whole system will be created.

3.2 Simulation

For the development of the software, mainly the MPC, a good simulation is needed for testing. For this project, that is provided through a collaboration with the SMaRC. Using their simulation environment in Unity a approximate rigid body simulation of the BlueROV2 will be created collaboratively using the mathematical models given in [22]. In the Unity environment, ROS2 topics are used for handling the information flow between the systems. This makes the transition from the simulation to the real BlueROV2 seamless.

3.3 MPC

As MPC is a very computationally heavy controller, for us to implement it onboard on the BlueRov, we will try to simplify the model of the BlueRov a lot to simplify calculations.

3.3.1 State Estimation and Kalman filter

The first plan is to use a state estimator provided by SMaRC that they use on their robot which utilizes a DVL and an IMU. Since we will implement a DVL and together with the built in IMU, this state estimator should work well. The only concern would be that this may be difficult to implement with regards to, as for the MPC, computing power available on the Raspberry pi. This is especially true with regards to the fact that we will have an MPC running in parallel. If this provided estimator does fail to be implemented or the computing power is proved to not be enough, further research will be put at either creating our own estimator or simplifying the provided one. A last resort would be to simply utilize the Motion capture system that SMaRC uses at their laboratory to capture the motion of the rover. This captured motion could then be manipulated to more closely resemble the signals that would have been provided from a Kalman Filter before being sent to the BlueROV.

3.3.2 Path Creation and Following

To actually be autonomous the ROV must navigate underwater which is a difficult problem to solve therefor it has been split into two parts, creating a path and following the path. The path creation will in this project not be done autonomously in the sense that the robot will not decide itself where it should or should not go, instead that will still be decided by the handler before it goes underwater. The path is defined by waypoints inside the operational area using at least to locations, The start waypoint which is the current location of the ROV and a number of points to visit along the way that can range from one and beyond.

The current state of the ROV can be described by a 12-dimensional vector describing its position and rotation underwater and its corresponding velocities and each waypoint could be defined using this 12 element vector. However after evaluating the purpose and scope of the project this has been reduced to only 4 DOFs meaning each waypoint will only be defined by its location in x,y,z and its rotation around the z-axis, also known as yaw which can be seen in equation 3.1.

$$\boldsymbol{p_i} = \begin{pmatrix} \boldsymbol{x_i} \\ \boldsymbol{y_i} \\ \boldsymbol{z_i} \\ \boldsymbol{\varphi_i} \end{pmatrix} \tag{3.1}$$

For the robot to understand where it needs to go next and how to get there the waypoints will, as previously mentioned, be connected via a 4 dimensional path. This path will be generated onboard the ROV using a spline interpolation and will be described using multiple piecewise continuous higher ordered polynomial to get a smooth path to follow.

Finally, the ROV will attempt to follow the sub-waypoints defined by the spline interpolation using the MPC. It will estimate haw far it can reach depending on the length of the receding horizon defined by the MPC and actuate its thrusters according to the controller.

3.3.3 Lower Level Controller

The plan is to still utilize the lower level controllers that control the thrusters on the BlueRov but implement a higher level MPC for path following. Instead of the output of the MPC being the individual thruster forces it will simply output the thrust in the cardinal x,y,z and yaw directions. It would receive the same inputs as would have come from a manual controller, but instead it now comes from our control algorithm.

3.4 Computer Vision

For the computer vision part, a combination of self-developed solutions and existing frameworks will be used.

3.4.1 2D Image Enhancement

For the image enhancement a deep learning model, as discussed in section 2.5.1, will be implemented since it is the SoTA within that field. As part of another course that two people within the group have taken, namely Deep Learning DD2424, they have developed a GAN for underwater image enhancement which will be used as a baseline and be further developed during the fall.

3.4.2 3D Image Reconstruction

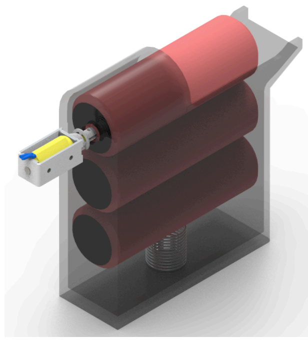
One of the best performing 3D image reconstruction from unstructured images are the NERF algorithms. During the fall, the open source program Colmap will be used with the enhanced images to create a 3D model of the archaeological sites. [23][24][25].

3.5 ULB Deployment Systems

Research was conducted to investigate state-of the art solutions for underwater payload deployment systems but not a lot was found. This was mainly due to confidentiality reasons as it seemed that a lot of the existing solutions were government-backed and only some patents were available publicly. None of the investigated patents, however, provided a simple and compact solution for the deployment of multiple payloads so the presentation of these solutions in the state of the art was not of interest. Instead, design inspiration was taken from ammunition magazines for the storage and feeding of ULB replicas, with the physical deployment being actuated electronically. Two separate design concepts were developed and are presented in this section, followed by a concept selection process.

3.5.1 Vertical Magazine

The first design concept, as depicted in Figure 3.1, is inspired by the vertical magazine of a machine gun. The three ULBs are placed on top of each other in the rectangular magazine shell, compressed by a spring. On the side opposing the spring, there will be an opening where one ULB at a time can be deployed by a solenoid. The idea is to place the magazine with the opening towards the ocean floor, next to the battery tube inside of the thruster frame. The preliminary weight of the system loaded with



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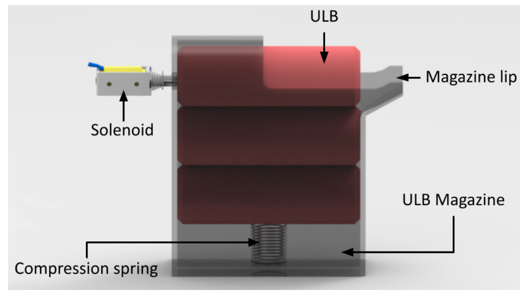
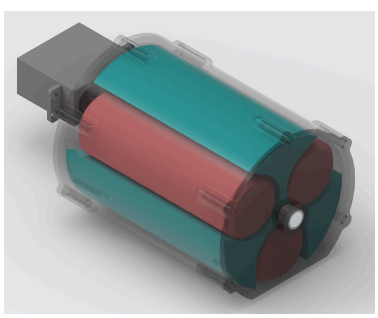


(b)

Figure 3.1: Linear magazine mechanism

3.5.2 Rotating Magazine

The second design concept, shown in Figure 3.2, is inspired by the rotating magazine of a revolver. It is a rotating magazine design where the three ULB's are placed in cylindrical cutouts that can rotate inside of a cylindrical shell which has an opening towards the ocean floor. The ULBs be released through this opening. The mechanism is actuated by a waterproof servo motor placed in the back of the magazine. The servo is then connected to an axle which the rotating magazine is fastened to. The axle itself is suspended with two slide bearings.



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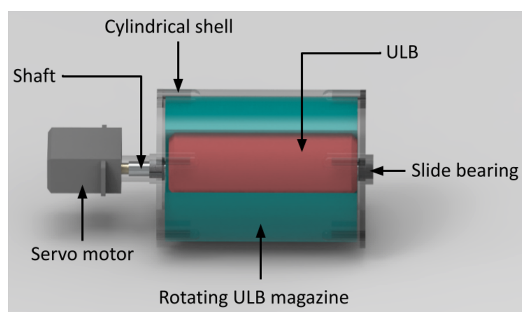

(b)

Figure 3.2: Rotating magazine mechanism

The preliminary weight of the system is 980 grams. One thing to note is that it is the weight for the system with the BlueROV2 mounts and screws excluded. The idea is to fit this mechanism within the UV where the robotic arm is placed today.

3.5.3 Concept selection

In order to select the best concept for this project our requirements where put in to a weighted decision matrix. All of the requirements was given a weight correlating to their importance, where 1 is the lowest importance and 5 is the highest. The concepts where then given a score from 1-5 of how well they fulfill the requirements, and the one with the highest score was chosen as the best fit for the ULB Deployment system. The evaluation matrix can be seen below in figure 3.3.

Concept Evaluation Matrix		Concept 1. Vertical Magazine		Concept 2. Rotating Magazine	
Requirement Criteria	Weight	Rating	Weight Score	Rating	Weight Score
Time between ULB deployments	2	4	8	4	8
Complexity	3	4	12	3	9
Modularity	3	3	9	4	12
Size	4	5	20	4	16
Total mass of system	5	5	25	4	20
Obstruction of thruster flow	5	5	25	5	25
Impact on mass distribution	5	3	15	2	10
Total Score		114		100	

Figure 3.3: Design evaluation matrix

The evaluation concluded that the vertical magazine concept was a better choice for the ULB deployment system. The physical development process will start during the autumn semester.

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A Risk analysis

FMEA of the risks in the project. A.1.

Item	Risk	Root Causes	Effect	Prevention	Probability (1-5)	Severity (1-5)	Detection (1-5)	Risk Priority
BlueROV2	Water in the tubes containing electronics	Not waterproof; poor sealing or cracks in the tubes	Development platform not functioning correctly.	Use checklist from BlueRobotics for pre operation testing. Don't go through the checklist alone. Handle ROV with care.	2	5	4	40
	Collisions damaging the ROV	Reckless driving of the ROV or faulty MPC.	Damage on the blueROV, its actuators or sensors.	Careful handling of the BlueROV. Have emergency stop. Test MPC with simulation before testing on ROV. Have an overview of the ROV when testing.	3	4	1	12
	Late deliveries of critical components	Not ordering on time, poor communication, logistics issues	Project delays. Missing deadlines.	Order as early as possible and communicate clearly	2	4	4	32
	Broken sensor DVL	Manufacturing fault, collision and/or water damage	No accurate state estimation	Software detection, regular calibration?, careful handling	2	4	3	24
	Broken tether contact	Reckless use and/or general mistreatment of the BlueROV	Project delays and potential BlueROV damage	Careful handling of the tether, increase robustness	4	2	2	16
	MPC is not able to run on the blueROV	RP4:s computing power is not sufficient	MPC will not be able to run on board	Try to minimize MPC computing requirements, optimize code, buy additional or other onboard computer. Or use topside computer	3	1	1	3
Testing and verification	No motion capture sensors available for position validation	SMaRC's pool with motion capture system is not available.	Can not verify the function of the MPC	Have a backup plan for pool and sensors.	4	2	2	16
	Unity simulation will not work	Faulty code	Very limited testing of the BlueROV software. Unable to simulate before testing in real life	Good communication with SMaRC	2	4	1	8
	Existing physical model(s) of BlueROV2 is insufficient	Modelling error(s) or insufficient detail	Delays in MPC and simulation development	Try to start testing on time	3	3	2	18
ULB release mechanism	Failure to waterproof the electronics	Unsufficent construction	Unable to use ULB release mechanism	Detailed testing to ensure waterproof	2	4	3	24
	Problems with actuator(s)	Electrical error, integration hell, bad quality	Unable to use ULB release mechanism	Purchase good quality with needed requirment ratings and make sure to be methodlical with integration	2	3	2	12

Figure A.1: Risk analysis

B Fall Term Plan

GANT chart for the fall term.

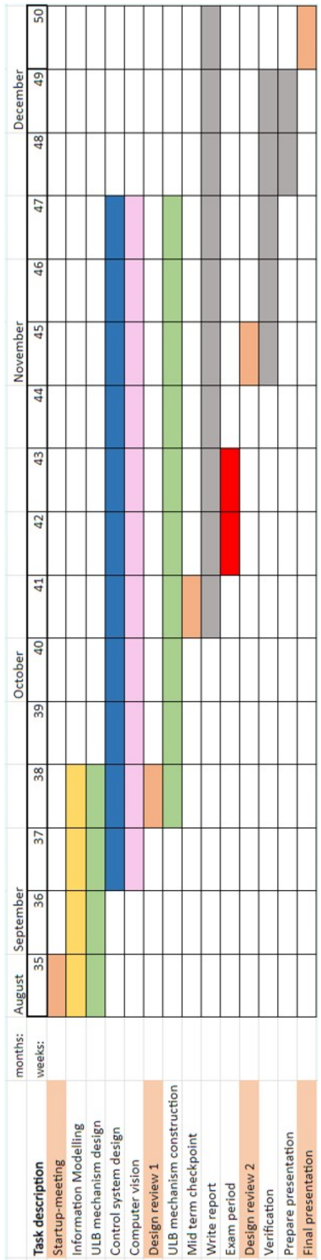

Figure B.1: Preliminary plan for the fall term