UNIVERSITY of HOUSTON

COLLEGE of TECHNOLOGY

Mechanical Engineering Technology

Fall 2024

MECT 4275 Senior Design Project I

Final Project Proposal

ROV Modular

Team 05

Student Team Members:

Crawford, Dakota R (1780849)

Guerrero, Nathan I (1904720)

Novak, Maxim (2062764)

Oviedo, Brett (1884788)

Soto, Ezequiel (1385474)

Final project proposal Submission Date: December 2nd, 2024

Table of Contents

Table of Figures 3

1. Executive Summary 1

2. Introduction 2

2.a) Motivation 2

2.b) Background 2

2.c) Adopted Technology 2

2.d) Problem Overview 4

2.e) Next Semester Goals 5

2.f) Technical Features 6

2.g) Project Scope 7

3. Design Strategy 8

3.a) Manufacturing considerations 9

3.b) Simulation Overview 10

3.c) Procurement considerations 11

3.d) Key Obstacles and Mitigation Strategies 12

3.e) Division of work among the team members 13

4. Cost and Schedule 14

4.a) Initial estimate for the project cost 14

4.b) Sponsor Outreach 14

4.c) Timeline for various objectives listed above (Gantt Chart) 16

5. Safety and Ethics 16

5.a) Safety Codes and Standards for Mechanical Carousels and Electrical Systems 17

5.b) Subsea Tool-Swapping and Automation 18

5.c) Ethical Considerations: Public and Operator Safety 18

5.d) Environmental Responsibility 19

5.e) Transparency and Honesty in Reporting 19

5.d) Consent and Safety Training 20

6. Skills Table 21

7. References 22

Table of Figures

Figure 1 Modular Schematic 4

Figure 2 CAD model with tool attachments 6

Figure 3 Section View of the Modular tooling device 7

Figure 4 Key description table 7

Figure 5 Welding aluminum practice 9

Figure 6 Static simulation at 100 m 11

Figure 7 Static simulation at 300 m 11

Figure 8 Breakdown of task 13

Figure 9 Cost estimate 14

Figure 10 Gantt Chart 16

Figure 11 Skills Table 21

1. Executive Summary

With the vastness of the ocean and the human body's inability to breath underwater, many industries have turned to ROVs for underwater operations. The world's oceans are the final frontier left to explore on earth, vast, expansive, and mysterious. The oceans are also very dangerous to explore, extreme temperatures, pressures, constant currents, and unfamiliar territories make the danger more difficult to assess and avoid. ROVs take much of the danger out by removing people from these conditions allowing us to explore and operate underwater more than ever with less risk.

A major aspect of any operation involving an ROV is the task the ROV is built to perform. Because of the extreme environments, tooling and tasks can be very limited. These limitations are due to time, size, and unforgiving conditions that each element of an ROV suffers from when in operation. The current market is very limited in the tooling they include on ROVs, making them limited in their working scope and inadaptable to changes and unforeseen circumstances due to the very limited tooling that a ROV can carry.

For this Senior Design Project, our team is focusing on the development of a modular tool changer system for light duty and inspection class ROVs. Due to the extreme conditions of deep-sea environments, we must consider high pressures and the changing behavior of metals in cold temperatures at high pressure. Moving sealing elements, and high-pressure enclosures need to be considered in the design, along with material buoyancy and size restrictions to be able to fit on existing ROV systems.

We will consider the pressures and temperatures that our system may experience. Proper materials selection and minimization of compressible gases and materials will allow for a system to remain watertight and operation under difficult conditions. We will also consider the costs of creating such a system as many deep-sea components are costly and may be able to be reduced in cost with simple techniques in mechanical design and material properties.

2. Introduction

2.a) Motivation

Our team is working on a modular, highly adaptable solution for light inspection and light operation class remotely controlled vehicles. The main idea of this design is to develop a system capable of remote switching of key components such as sensors, cameras, and manipulators without the need for resurfacing of the ROV. This feature is important for the purpose of minimizing downtime and enhancing operational efficiency in deep-water operations or when time becomes a critical factor. This also increases operational flexibility.

To enable this, the ROV will be equipped with an easy docking and connector system that permits fast changes in a submerged position. Mechanisms will have standard interfaces that allow plug-and-play capability; hence, it is easy to switch parts remotely from a surface control unit. It will involve mechanisms in the communication protocol to ensure that whatever component is active fits into the current hardware and software architecture of ROV without manual recalibration or reconfiguration.

2.b) Background

In the ROV industry few solutions are available for a tool changing platform that works while the ROV is underwater. Currently the only commercially available system is the Schilling FMC Gemini ROV which uses an internal carousel of 31 tools (1) (2). The Gemini system is unfortunately very costly to run and about the size of a small to mid-Sized SUV making it limited to very specialized operations usually in oil and gas industries (1) (3). No such systems are available for smaller ROVs.

2.c) Adopted Technology

Our project, developed by communication with industry mentors and leaders, allows the ROV-olver to reach a depth of 100 meters while maintaining full operational capability and being exposed to pressure and environmental conditions within the depth of 100 meters. To achieve this depth, the design and materials are the most vital specifications we are taking into consideration. With material selection being a crucial specification, we must still meet the requirements of designing and creating a watertight, pressure resistant, reliable, and durable modular system that can also have the reputation of longevity.

The tools that will be integrated within the ROVolver are solely chosen for inspection class ROV's. As of right now, we are examining tools that can perform these tasks that inspection class ROV's complete. The tools we are considering are as listed below:

- Robot Hand Gripper
- Camera
- Calipers
- Rotating Cleaning Brush

These four specific tools are the most vital when it comes to inspection class ROV's per our communication with Boxfish Robotics. As stated in the previous paragraph, our tools must be selected precisely to live up to the depth, reliability, and longevity of the modular ROV system.

Being able to attach this modular tool system to either existing or new ROV's requires a compact yet reliable modular system that takes size, shape, and weight into our design and material selection. With that being said, the smaller and lighter modular tool system is, the increase of versatility this component will be for existing ROV operators. With this specific compact system, the maneuverability of the ROV should either be minimal or negligible due to the difference in weight from being underwater as compared to the owner holding the ROV. Having the ability to connect the ROV-olver to existing ROV's will substantially increase the efficiency and productivity of all inspection class ROV's due to the simplicity of the attaching and detaching of tools.

When it comes to communication within the modular tool system, we will be using standard communications protocols such as voltage and Ethernet IP connections for easy connections between newer/older ROV models.

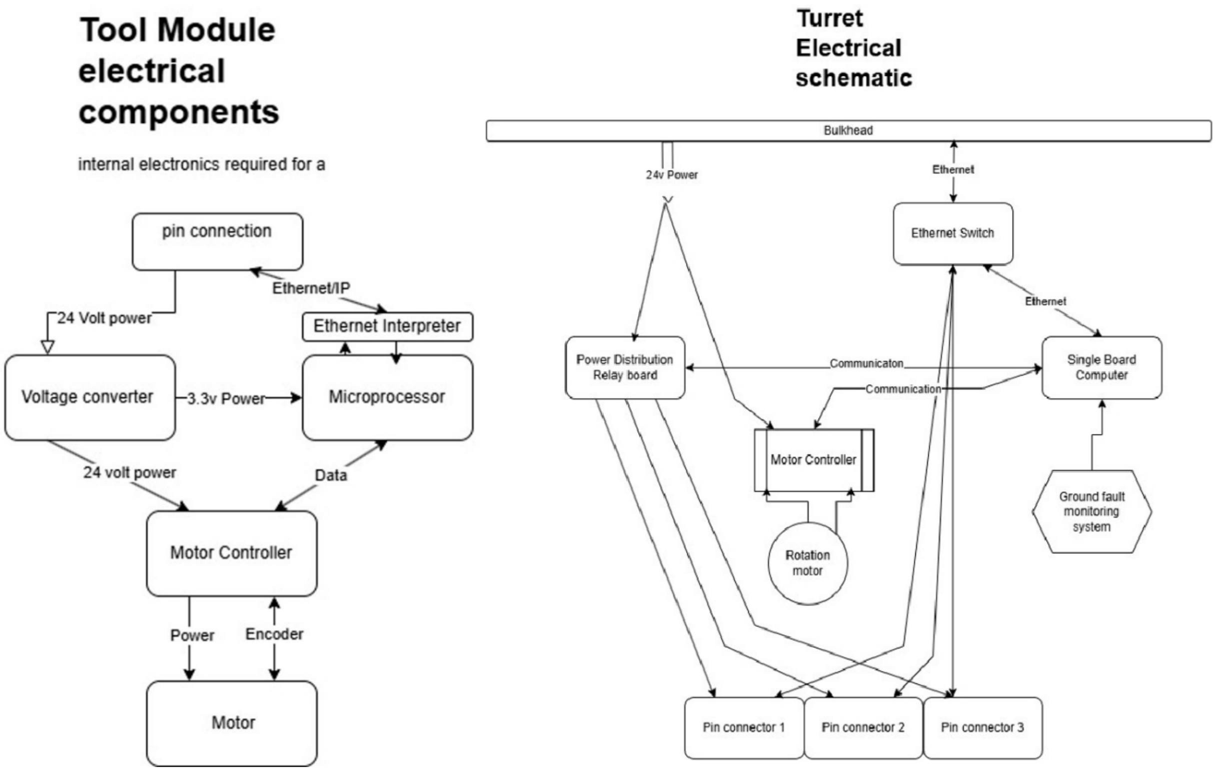

Figure 1 Modular Schematic

The electrical system will be comprised of the turret side and the tool side system. The turret side system will have a single board computer (SBC) that controls a power distribution relay board and an ethernet switch. The SBC will control the motor and spin the turret, each turret tool holder position will have a hall-effect sensor to detect the presence of a module in the system, a ground fault detection circuit will confirm the connection using a separate microcontroller measuring the tool resistance between power and ground, if the resistance drops below acceptable levels the tool power and connection will be disconnected (4). On the tool side, a microcontroller will handle the ethernet connection and based on its function execute the necessary tasks.

2.d) Problem Overview

The limitations of existing light-class ROV options are that they cannot change tools without returning to the surface. Since the requirement for ROVs to return to the surface to change tools out involves a great deal of downtime and operational inefficiency, both time and financial resources are wasted. This detracts from the effectiveness and flexibility of an ROV in dynamic underwater environments where the conditions and operational requirements might change in a very short time. Although tool-changing systems already exist-such as the Gemini carousel system-these are clearly beyond the price range-up to $15 million in some cases (1) (3). Equipped with up to 33 tools, with the assistance of a sophisticated carousel and robotic arm fitted with magnetic and hydraulic couplings, the big working-class ROVs for which the Gemini system is designed can operate at near record depths (1). However, the expense and complexity of this method make it unreachable for light-class ROVs, which are usually smaller and only very slightly equipped with the most basic tools, because their typical task is in-water inspection.

Our work aims to develop a modular, affordable tool-changing system for light and inspection-class ROVs to fill this gap. Increased carrying and switching of equipment will allow the enlargement of operating breadth and productivity of these smaller ROVs significantly. This would reduce the need for resurfacing and thus increase the utility of the vehicles in several subsea applications.

2.e) Next Semester Goals

For the next two semesters our group aims to design and develop a rotating tool carousel that allows for seamless underwater tool switching. This project focuses on creating a modular system where multiple tools, cameras, or manipulators can be pre-mounted on a rotating turret, enabling the ROV to quickly adapt to various tasks without needing surfacing or manual reconfiguration. By addressing common challenges like downtime and limited flexibility in traditional ROV designs, our goal is to build a multi-functional tool for smaller ROVs that can handle a range of operations, from inspections and environmental monitoring to minor interventions. Through this project, we aim to showcase the potential for greater adaptability in ROV's and offer a proof-of-concept design in modular tool systems aimed at industries such as oil and gas, marine research, and underwater exploration.

2.f) Technical Features

The project goal is to be able to create a system that can operate at a depth of 100m. The operation includes using all four devices and being able to rotate the turret to swap between them. The turret should be operated using ethernet IP and should be transparent to the devices on the turret meaning they appear as standard devices on an IP network.

Figure 2 CAD model with tool attachments

For the tools, they should each be able to be removed above water easily with a simple set screw. The tool and its electrical components should be waterproof and be able to operate without fail while at depths of 100m. When the modular tool system switches between the different tools the system should automatically detect whatever tool is currently in the forward position and switch its controls based on the tool.

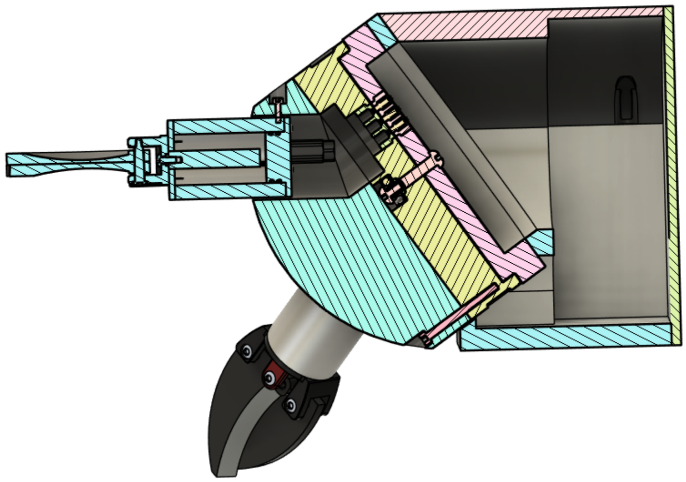

Figure 3 Section View of the Modular tooling device

Legend	
Color	**Description**
(blue)	Removable head that holds the attachments on the turret.
(peach)	Stainless Steel binding hex screw
(green)	Female Pogo Pin Connectors Base
(pink)	Holds the male Pogo Pin Connectors & base attachment to the turret

Figure 4 Key description table

2.g) Project Scope

Our project's scope involves developing a design that is prepared for testing and manufacture as well as finishing simulations to give preliminary estimations of the system's depth capabilities. We are constantly looking for sponsorship options in addition to the design and simulation work, contacting different businesses with the goal of obtaining money before December. This sponsorship will be essential for acquiring the supplies required to start the system's actual development. To create a modular communication system for our tool-changing design, we are also now researching Ethernet/IP technologies. By early December, we want to have a solid grasp of this technology, which will enable us to start the coding phase in November or December. With an early start, we want to finish the coding process by February, though we expect it to take some time.

We will start building the modular design as soon as we have the required materials, which we intend to complete by the beginning of December. In the early months of 2025, we want to prototype and build the system over the winter break. This schedule will provide us enough time to polish the prototype, waterproof the parts, and guarantee that the system works flawlessly well in advance of our final deadlines.

3. Design Strategy

The design of our modular tool system will be based on a CNC mill tool change revolver with multiple tools evenly spaced around. This will eliminate the need for resurfacing and reduce downtime for tool change without reducing performance. By reaching out to different companies, we will be able to narrow down on specific tools in rotation, a focused depth, and design considerations that will act as a pathway when creating the modular tool system. This will ensure that our design is geared towards a targeted market for inspection ROV's.

The team will be using power tools, hand tools, and welding machines for mechanical purposes. More specifically, AC aluminum Tig welding will be used for joint together pieces of aluminum. Impact drivers and drills with adjustable torque ratings for accurate support. The software's implemented for designing will consist of SolidWorks and Fusion 360. For prototyping and fabrication, Pruda Slicer, 3D printers, CNC machines, metal benders, and lathes will be used. For programming and electrical components, Raspberry Pi single board computer, ethernet switch, relay boards for power control, DC motors, and a rotary encoder will be used.

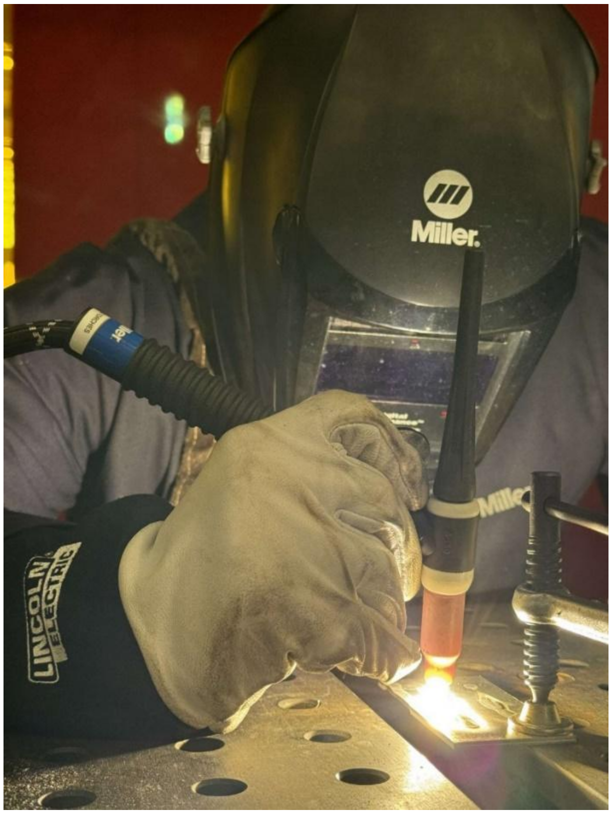

Figure 5 Welding aluminum practice

3.a) Manufacturing considerations

As part of our goal, we are attempting to make this design low maintenance, low cost, but everlasting. Parts need to remain as standard as possible, especially sealing elements like O-rings and radial shaft seals. Parts need to be manufactured carefully, and sharp edges removed to ensure adequate seals can be made. Parts must be able to withstand high pressures, minimizing any holes and interfaces to create better pressure sealing characteristics. The elimination of any empty spaces is necessary for the purpose of reaching greater depth. This will be achieved by machining parts with precise tight tolerances. As well as filling that empty void with mineral oil (5) (6).

The materials used must be corrosion-resistant and high-strength to handle harsh high pressure and saltwater environments. For any non-metal materials, the choice of high-density non-reactive plastics such as high-density polyethylene will be considered strictly for weight reduction and high-water resistance (3) (5).

3.b) Simulation Overview

The simulation was conducted using SolidWorks Simulation to evaluate the structural behavior of the assembly under realistic underwater conditions. To mimic the assembly's connection to a ROV, the top portion was fixed in a permanent position. To represent ocean pressures, external loads of 3,016,575 Pa at 300 meters and 1,004,151 Pa at around 100 meters were applied. To evaluate deformation and stress distribution, static simulations were run with the shell empty. The maximum strain recorded during the simulation was 0.003858 at 100 meters and 0.08784 at 300 meters, highlighting the increased deformation at greater depths. An incompressible fluid, such mineral oil (6), is inside the shell to reduce stress and deflection. The materials used in the ROV modular design—PE High Density, 6061 Aluminum Alloy, and Nickel Silver 65-12—were selected for their specific mechanical and physical properties, making them well-suited for underwater applications at depths of 100 to 300 meters. PE High Density is perfect for parts subjected to constant submersion in water because it provides superior buoyancy, corrosion resistance, and impact resistance. Because of its exceptional corrosion resistance, high strength-to-weight ratio, and structural stability, 6061 aluminum alloy is especially well-suited for load-bearing parts that must withstand the rising pressures at depth. The pogo pins are made of nickel silver 65-12, which has exceptional conductivity and corrosion resistance, guaranteeing dependable electrical connections in submerged conditions. These materials work together to combine corrosion resistance, lightweight design, and longevity, enabling the ROV modular design to function efficiently while maintaining structural integrity and operational reliability under significant hydrostatic pressures (3) (5).

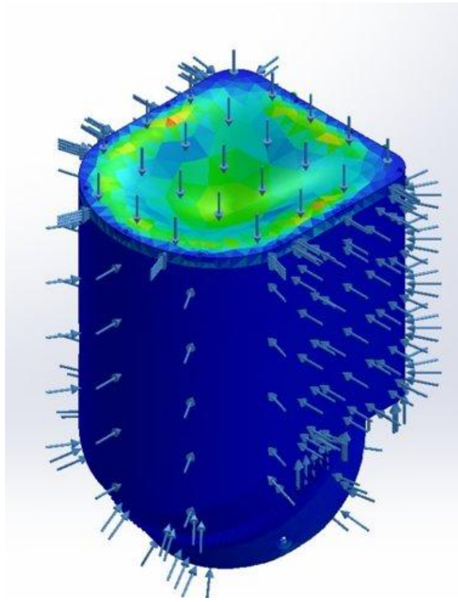

Figure 6 Static simulation at 100 m

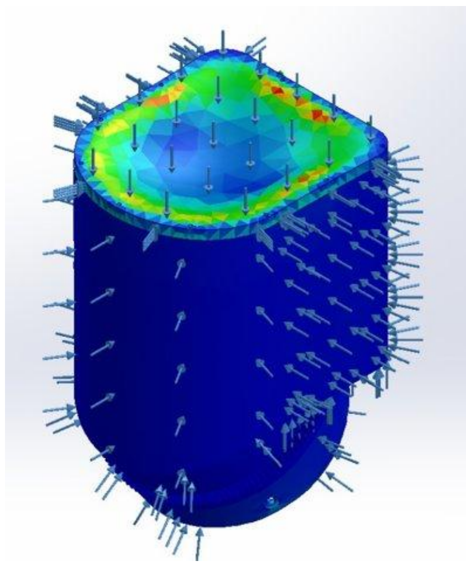

Figure 7 Static simulation at 300 m

3.c) Procurement considerations

During this semester of planning, the team is working towards finding the best procedures to mitigate high spendings. By forming strong relationships with sponsors and parts suppliers, our team can get approval for potential deals and discounts. So far, our team has managed to receive a 15 percent discount from Blue Robotics on parts ordered through their website.

As part of our goal states low cost, our plan is to assign more products to a limited number of suppliers so we can avoid overspending and reduce shipping costs. In-house machining and fabrication will also be our focus for any custom parts to stay within budget. Our team is also outsourcing leftover materials from nearby company's previous projects to avoid overspending on materials and shipping cost. Our team is in the process of learning all the machines on the shop floor as well as 3D printers and milling machines in the labs. Some of our team members will also be attending training classes with third party companies on specific machines in our shop. Our attempt will be to fabricate all parts possible in the workshop without supervision or a technician onsite overlooking our work.

3.d) Key Obstacles and Mitigation Strategies

The most challenging part of the project is making the modular tool system waterproof and able to withstand high pressures. Parts may need to be filled with a dielectric incompressible fluid to minimize pressure differentials. Correct parts from manufacturing must be carefully considered. Potential sponsors need specific information and good communication through the university to supply an ROV for testing purposes. Camera placements need to be carefully considered for field of view and tool visibility for precise work. The weight in water of the modular tool system needs to be considered for integration with an ROV as opposed to weight in air. Materials being used will have to be selected based on targeted depth range.

Our team is currently sectioned into assigned tasks to cover all aspects of the project at the same time. Weekly meetings are set up to relay important information and inform the team of any problems/complications. In these meetings, we discuss our roles for the upcoming weeks and plan head of time to reduce overlapping and uncertainty. We also structured a group chat and Microsoft Teams channel with Carlos Ayala where all files and data, discussions, progress updates, and any markups pertaining to the project are posted. Meeting minutes are also captured for every meeting to keep track of key talking points, important changes, and promote transparency. The meeting minutes are structured in the following format: attendance, summary, general notes, individual weekly updates, key topics, and key questions.

3.e) Division of work among the team members

Max Novak is doing software and electrical development. Nathan Guerrero is tasked with design and implementation. Ezequiel Soto is the team's communication and technical writer. Dakota Crawford and Brett Oviedo are material testing and fabrication engineers.

	Design	Simulation	Calculation	Program	Fabrication	Budget	Communication
Brett	•				•		
Dakota	•				•	•	
Ezequiel						•	•
Maxim			•	•			
Nathan	•	•				•	•

Figure 8 Breakdown of task

4. Cost and Schedule

4.a) Initial estimate for the project cost

Initial estimates below are based on preliminary component considerations.

Components	Quantity	Cost	Total cost
Electrical			
RasPi SBC	1	$ 69.00	$ 69.00
Microcontrollers	5	$ 28.00	$ 140.00
motor driver	1	$ 10.00	$ 10.00
motor	1	$ 25.00	$ 25.00
Worm Gear	1	$ 20.00	$ 20.00
worm gearbox	1	$ 30.00	$ 30.00
encoder	1	$ 12.00	$ 12.00
cabling	1	$ 35.00	$ 35.00
Pogo Pins F	10	$ 2.00	$ 20.00
Pogo Pins M	25	$ 2.00	$ 50.00
Hall effect sensors	6	$ 8.00	$ 48.00
Power distribution boards	2	$ 65.00	$ 130.00
Ethernet switch	1	$ 65.00	$ 65.00
Voltage Converters	6	$ 18.00	$ 108.00
Bulkhead connectors	8	$ 85.00	$ 680.00
Mechanical			
Aluminum Billet	1	$ 540.00	$ 540.00
oRings	15	$ 1.00	$ 15.00
Gasket material	20	$ 1.00	$ 20.00
Mineral Oil	1	$ 40.00	$ 40.00
Plastic Stock	1	$ 60.00	$ 60.00
Wire Penetrator	3	$ 5.00	$ 15.00
Brushless motor (for Modules)	3	$ 20.00	$ 60.00
Drill Brush Attachment	1	$ 10.00	$ 10.00
M4 screw Set	1	$ 30.00	$ 30.00
3D Fillament	4	$ 20.00	$ 80.00
Resin Epoxy	2	$ 20.00	$ 40.00
Shaft Bearing	2	$ 80.00	$ 160.00
Gripper Head	2	$ 12.00	$ 24.00
TOTAL			$ 2,536.00
BlueRobotics ROV2			$ 3,683.75
TOTAL w/ ROV			$ 6,219.75

Figure 9 Cost estimate

4.b) Sponsor Outreach

We have actively pursued potential sponsors within the subsea and ROV (Remotely Operated Vehicle) industries to support our senior design project, specifically targeting organizations that specialize in underwater robotics and marine engineering. Our objective is to get sponsorships that will enable us to improve the development of our modular ROV tool system by offering us material resources and technical advice.

One of our most promising relationships was with Brett Jenssen, the Operations Manager at DeepOcean. Mr. Jenssen, who is currently serving more as a technical advisor, has provided insightful counsel. Along with his advice, he has invited us to tour their workplace, which will provide us with more knowledge about how they run their business and how our idea may fit in with industry demands. Even though we are still talking to DeepOcean about sponsorship prospects, Mr. Jenssen's participation has already been a great help to us. Similarly, Jelmer de Winter from Fugro has also been in communication with us, offering guidance on material selection and input on potential enhancements for our rotating mechanism. Despite Fugro's lack of a ROV presence in Houston, Mr. de Winter recommended that we get in touch with Seatronics, another business that is well established in the subsea industry. We've reached out to Seatronics and are expecting a response about possible sponsorship.

Furthermore, we have had discussions with TechnipFMC and Oceaneering, and we have had a useful discussion over Teams and in person. Opportunities for technical assistance have been offered to us but no monetary sponsorship (5). Technip did have us travel to their energy corridor location to test out their VMAX Simulation which is a computer simulation of real-world ROV control systems and mission used to train ROV pilots. In addition to subsea industry relationships, we have contacted manufacturing firms like Kystodesign for additional possible gear mechanisms and Anaheim Automation for worm gearbox options. The parts needed for the mechanical component of our design might be supplied by these businesses.

Even though we haven't signed any official sponsorship agreements yet, the connections we've made with Mr. Jenssen and Mr. de Winter have been crucial in helping us steer our initiative. As we continue to interact with business executives and manufacturing specialists, we are hopeful about upcoming sponsorship prospects.

4.c) Timeline for various objectives listed above (Gantt Chart)

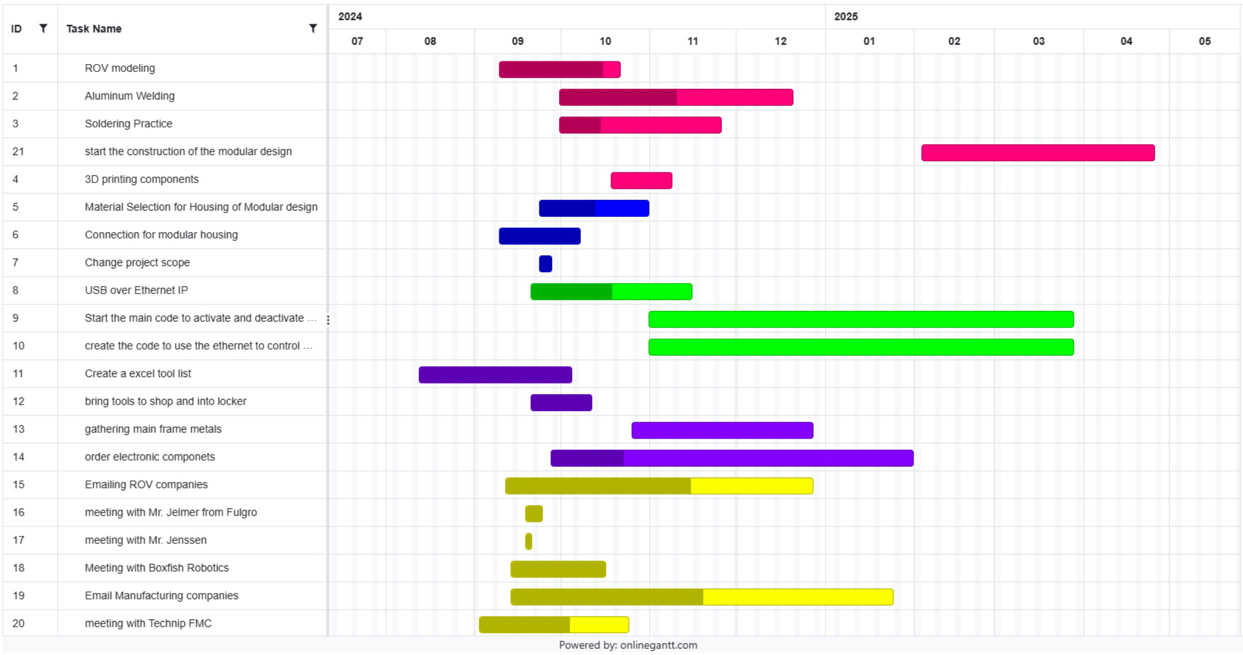

Figure 10 Gantt Chart

5. Safety and Ethics

Any engineering project should involve designing for safety and ethics, but this is particularly true when working with complex systems such as a modular tool system utilizing a rotating head. Besides being a technical requirement, there exists an ethical requirement in ensuring safety to operators and the public and minimizing environmental harm. The application of accepted safety regulations and standards aids in ensuring that the equipment functions as designed within a range of operational conditions, minimizes the occurrence of accidents, and protects the environment. Ethical considerations foster transparency and accountability; likewise, engineers are led to present the risks and limitations of their designs. Success and ethical viability depend upon our assurances that such systems are reliable, sustainable, and responsibly used conditions accommodated by adherence to established safety regulations and guidelines relating to ethics.

5.a) Safety Codes and Standards for Mechanical Carousels and Electrical Systems

The design of the multi-tool changing carousel to be integrated with an observing remotely operated vehicle will be performed in compliance with critical safety regulations and standards regarding mechanical and electrical systems. *ISO 13628-8* covers the Petroleum and Natural Gas Industries and is titled *Design and Operation of Subsea Production Systems (9)*. Whichever subsea equipment is under consideration, including ROVs, safe design and operation will be emphasized. This standard ensures safety in tool carousels, tool protection, and the safe functioning of switching mechanisms when submerged under water. In this regard, to avoid problems, the wear, pressure, and mechanical stresses must be overcome. *ISO 12100* deals with general principles of equipment safety design, risk assessment, and risk reduction, basically covering the promotion of the safe design of equipment, identification of risks, and reduction (9). It provides recommendations to reduce the hazards associated with moving elements, including safety guards, redundancy systems, and emergency stops integrated into the carousel.

IEC 60204-1 (Safety of Machinery - Electrical Equipment of Machines)(10) stipulates the requirements of electrical safety with respect to control systems, wiring, and grounding practices. It states that the electrical parts of the carousels should be designed to sustain electrical risks such as fire and shock incidents: motors and control circuits (10). Furthermore, *API RP 17H* also provides general guidelines that must be followed when safely operating ROV tooling and interfaces in subsea environments. Conformity to this document will ensure safe and efficient adoption of the multi-tool carousel, with its design adhering to the current state of subsea tooling. Compliance with *IEEE 1010* is essential in electrical installations designed only for ROVs, which is quite necessary for maintaining operating safety for motors and sensors together with power systems when submerged to avoid electrical hazards of short circuits (11). The fact that the ROV is remotely operated does not make *OSHA 1910 Machinery and Machine Guarding* inapplicable, hence machine guarding, and fail-safe mechanisms are considered for protection during maintenance and other personnel activities (11). *NFPA 70* is the basic code in the construction of electrical systems for marine applications, which provides assurance of conformance to safe wiring, grounding, and short circuit protection (12). All pressure-sensitive components, such as hydraulic actuators or sealed electronics, must be designed and manufactured against specifications to support deep-sea pressures according to the *ASME Pressure Vessel Code standards PVHO-1 (12).*

Finally, equipment deployed in underwater environments shall be designed to avoid the infiltration of water into mechanical and electrical systems by meeting appropriate *Ingress Protection (IP) Ratings*, particularly *IEC 60529*; it is desirable to have an *IP69* rating for applications involving continuous submersion (9). To be certain that the subsea equipment will meet the performance and safety requirements for the operational environment, it is necessary to be guided by *DNV-RP-E101*, Recommended Practice for Subsea Equipment Qualification. Together, these suggestions help your multi-tool changing carousel last longer, be safe, and function well in water.

5.b) Subsea Tool-Swapping and Automation

Addressing the danger of accidental activation is crucial for automation and subsea tool interchange. Safeguards should be designed in the multi-tool carousel to avoid the inadvertent activation of tools, especially those with moving elements like cutters or manipulators. Fail-safe devices and interlocks will provide a method to ensure that tools are activated only when required, reducing the possibility of accidents. Redundant control systems should also be installed for operations important to safety. These systems provide a fallback in case of failure of, for example, a motor or switching mechanism. If there is a breakdown, the ROV should be able to safely shut down the carousel or bring it to the surface. Most incidents may require mechanical fail-safes or backup power to ensure safe functioning.

5.c) Ethical Considerations: Public and Operator Safety

The *NSPE Code of Ethics for Engineers* emphasizes that the primary responsibility of engineers is to protect the safety, health, and welfare of the public (9). Ensuring the safety of both the public and operators is a vital consideration. When designing the multi-tool carousel, it is imperative to account for the safety of operators, maintenance personnel, and environmental stakeholders alike. First, before ROV deployment, there must be proper risk analyses implemented in line with ethical engineering standards to identify possible hazards such as entrapment issues, tool failure, or loss of power. In relation to the protection of all parties concerned and maintenance of ethical norms of engineering, these hazards should be reduced and minimized.

5.d) Environmental Responsibility

In a multi-tool carousel development for ROVs, one of the most critical considerations involves minimizing impact on the environment in sensitive marine ecosystems. In design, priority should be given to eco-friendly materials that would not discharge dangerous chemicals to the water. Moreover, carousel and ROV operations need to be as noiseless as possible, because too much noise may damage marine life, particularly species relying on sound for communication and navigation (9). Of equal importance is ensuring the ROV operation does not impact sensitive underwater habitats through silt disturbance or other forms of damage to coral reefs. The ROV must, therefore, avoid disrupting the wildlife it might encounter by following restrictions such as the *MMPA (Marine Mammal Protection Act)* and *MARPOL* when operating in areas subject to environmental preservation laws that prevent pollution (8). Following these regulations, along with a regard for the vast ecological reach the device has, allows engineers to contribute to the preservation of marine ecosystems while still performing efficient ROV operations.

5.e) Transparency and Honesty in Reporting

Transparency is necessary when providing industrial partners with information about the multi-tool carousel's capabilities and limitations, particularly during marketing or demonstrations. The safety, effectiveness, and environmental impact of the tool-switching process must be correctly portrayed. Not only is it unethical, but misrepresenting these factors to stakeholders might lead to operational breakdowns or field safety risks. Stakeholders and end users should be adequately informed of any potential issues, including misaligned tools, mechanical wear, and other operational issues. By describing these limitations in simple words, engineers may encourage trust and ensure that users are fully aware of the system's performance. This will lower the possibility of abuse or unforeseen malfunctions and help people make better judgments. Maintaining engineering ethics is also aided by open communication and aligning with professional responsibilities to safeguard both users and the environment.

5.d) Consent and Safety Training

Thorough training is necessary for all team members and operators who operate or maintain the ROV with the multi-tool carousel. To properly handle possible problems, this training should go over the system's functionality as well as important safety precautions, such as emergency protocols. Giving users clear instructions guarantees that they are aware of the hazards and capabilities of the system, which is the technical team's ethical duty. Appropriate training protects the equipment and the personnel by increasing operating efficiency and lowering the chance of accidents. The particular technical abilities required for the multi-tool ROV carousel's effective deployment and upkeep should also be covered in training. This entails employing the proper safety equipment when doing jobs like welding, handling mechanical and electrical components properly, and comprehending the underwater tool-switching system. To produce long-lasting components, specialized expertise in CNC machining and underwater welding is essential. To guarantee that the system stays functional and watertight, all team members also need to be knowledgeable of emergency procedures and regular maintenance. This thorough training will guarantee the multi-tool ROV carousel runs effectively and safely while lowering hazards.

6. Skills Table

Rate Mechanical Engineering skills or knowledge required for the project, based on the following scale:

1 = Must have

2 = Helpful, but not essential

3 = Either a very small part of the project, or relates to a “bonus” feature

Blank = Not applicable to this project

ME Knowledge / Skills required for the Project			
1	3D CAD	1	Computational fluid dynamics
2	Basic machining	3	Arduino
2	Statistics	1	GD&T
1	Materials selection	1	Selection/Usage of Sensors
1	Selection of Manufacturing Process	1	Basic Electronics & Electrical Systems
	Stress analysis	1	Modeling of electromechanical systems
2	Static/dynamic analysis	2	Measurement & Data Acquisition
2	Thermodynamics	3	Biomaterials
1	Fluid dynamics	1	Ethernet communication integration
2	Heat transfer	1	soldering
1	Coding	1	Robotics
1	Welding	2	Circuit Design
1	Finite element analysis		
1	Machine elements		
2	Failure Criteria (Static and Fatigue)		
2	3D Printing		

Figure 11 Skills Table

7. References

1. **Janssen, Brett.** Deep Ocean Operation Manager. *Personal Communications*. Microsoft Teams, Houston : University of Houston, September 20, 2024.

2. **Schilling Robotics GEMINI ROV System. [Online] 2021. https://www.technipfmc.com/media/0kanstvt/data-sheet_schilling-gemini_rev4.pdf.**

3. Lovering, Denzill. TechnipFMC RI / ROV Operations Manager. *Personal Communications.* Microsoft Teams, Houston : University Of Houston, October 24, 2024.

4. Ground Fault Detection on an ROV. *Electrical Engineering Stack Exchange.* [Online] January 11, 2024. https://electronics.stackexchange.com/questions/696932/ground-fault-detection-on-an-rov.

5. Fox, Kenneth. TechnipFMC RI / ROV Operations Manager. *Personal Communications.* Microsoft Teams, Houston : University of Houston, October 24, 2024.

6. Waterproofing your Electronics Project. *The Cave Pearl Project.* [Online] March 17, 2023. https://thecavepearlproject.org/2023/03/17/waterproofing-your-electronics-project/.

7. Spittle, Blake. Using ROVs to image underwater infrastructure for structural integrity. *Environmental Science Engineering Magazine.* [Online] June 20, 2020. https://esemag.com/infrastructure/rovs-image-underwater-infrastructure-structural-integrity/.

8. Baldoni, Joe. Underwater ROVs: What Are They and How Are They Used? *JF Brennan.* [Online] August 2, 2022. https://www.jfbrennan.com/blog/underwater-rovs.

9. International Standards Organization. Part 8: Remotely Operated Vehicle (ROV) interfaces on subsea production systems. *Petroleum and natural gas industries — Design and operation of subsea production systems.* 2002. Vol. 1. ISO 13628-8:2002.

10. Safety of machinery - Electrical equipment of machines - Part 1: General requirements. *IEC 60204-1:2016.* s.l. : International Electrotechnical Convention, 2016. 6. ISBN 9782832236215.

11. List of Machine Safety Standards. *Machine Safety Specialists*. [Online] https://www.machinesafetyspecialists.com/u-s-safety-standards/list-of-machine-safety-standards/.

12. EN IEC 60204-1 Safety of machinery – Electrical equipment of machines – Part 1: General requirements. *DLS Electronic Systems Inc*. [Online] https://www.dlsemc.com/iec-en-60204-1-safety-of-machinery-electrical-equipment-of-machines-part-1-general-requirements/.