EGH400 Project Proposal: Scope of Work

Development of a Small-Scale Underwater Remotely Operated Vehicle (ROV)

Faculty of Engineering

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Unit Code:	EGH400 - Research Project 1
Assessment:	#1 - Project Proposal
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This proposal is submitted in partial fulfilment of the requirements for EGH400.

Contents

Acronyms

AUV Autonomous Underwater Vehicle. 3–5

CAD Computer-Aided Design. 5

CFD Computational Fluid Dynamics. 5

DOF Degrees of Freedom. 2, 5

GUI Graphical User Interface. 6, 7, 9

IMU Inertial Measurement Unit. 3

ML Machine Learning. 1, 4–7

PID Proportional-Integral-Derivative. 4, 6

QUT Queensland University of Technology. 1, 5, 8

ROS Robot Operating System. 4

ROV Remotely Operated Vehicle. 1, 3–7, 9

1 General Objective

This project aims to address a gap in the availability of small-scale, research-grade Remotely Operated Vehicle (ROV) platforms by designing, developing, and validating a small scale underwater ROV. The primary objective is to create a fully operational vehicle for use in Queensland University of Technology (QUT) demonstrations and as a testbed for novel Machine Learning (ML) control pipelines. The research will investigate hardware and software solutions that enable robust functionality in a compact form factor, a challenge not fully addressed by larger, commercially available systems or existing white papers.

2 Literature Review

2.1 Introduction

Unmanned Underwater Vehicles (UUVs) have become indispensable tools for a vast range of applications, including oceanographic surveys, infrastructure maintenance, and military defence [9, 22]. As technology has advanced, these vehicles have evolved from simple teleoperated platforms into complex autonomous systems capable of executing sophisticated missions [9]. However, the literature reveals that a significant portion of research and commercial development has focused on large-scale, work-class vehicles or highly specialised Autonomous Underwater Vehicles (AUVs), which are often financially and logistically inaccessible for educational institutions or rapid prototyping research [25]. This is due to the cost of setting up demonstrations with large scale ROV and larger ROV designs call for larger scale prototyping solutions which may not be realistic. This has created a gap for small-scale, low-cost, and modular ROV platforms that are not only suitable for demonstration but are also powerful enough to serve as testbeds for advanced control and perception algorithms. The aim of this review is to explore the current state-of-the-art in small-scale ROV design by analysing key themes in existing literature, thereby identifying best practices and informing the design methodology for a novel research platform.

2.2 Methodology and Scope

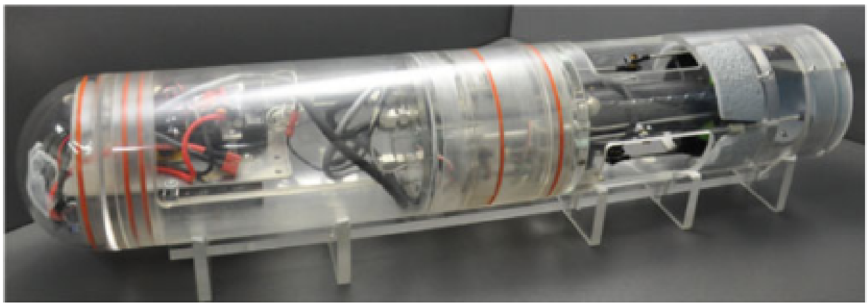
The literature review was conducted using a systematic approach, focusing on peer-reviewed journal articles, conference papers, and technical reports from the last decade. The search was primarily conducted using the database IEEE Xplore, with keywords including "small-scale ROV", "underwater vehicle design", "ROV control systems", and "modular underwater robotics". The review is structured to cover key design themes, hardware and software selections, control system architectures, and system modelling approaches, providing a comprehensive overview of the current state of small-scale ROV research. The scope of this review is limited to reviewing current literature on ROV design methodology and hardware selections. It is important to consider that methodology on improving autonomy algorithms, underwater communication, underwater vision processing pipelines and control modeling are valid current gaps that could be explored in future work.

2.3 Key Design Themes

2.3.1 Chassis and Mechanical Design

The physical architecture of an ROV is a foundational design choice that dictates its hydrodynamic performance, modularity, and durability. The literature presents a clear dichotomy between open-frame and enclosed, torpedo-style chassis designs.

(a) Open-frame chassis (eROV)[7]

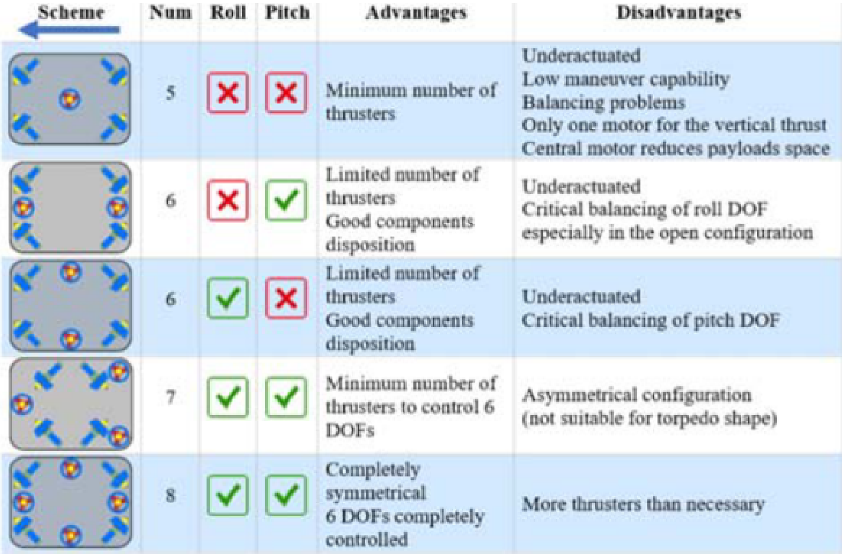


(b) Enclosed hull design (MASUV-1)[14]

Figure 1: Examples of ROV chassis designs: (a) open-frame and (b) enclosed hull

Open-frame designs, such as those seen in the KCROV [8], MarmaROV [24], and eROV [7], are praised for their modularity, allowing for easy mounting of sensors, payloads, and thrusters. This configuration simplifies maintenance and is highly adaptable for research platforms. In contrast, streamlined, enclosed hulls are often selected to minimise hydrodynamic drag for greater efficiency and speed, as demonstrated by the MASUV-1 [14] and X4-ROV [29].

The thruster configuration is critical for maneuverability, with designs ranging from underactuated 3-thruster systems providing basic 3-Degrees of Freedom (DOF) motion [27], to fully actuated 6 or 8 thruster systems enabling full 6 DOF control [16, 18]. The placement of thrusters in a vectored arrangement is common for achieving high agility, allowing for coupled control of surge, sway, and yaw from a set of horizontal thrusters [12, 25]. Figure 2 illustrates the impact of different thruster orientations on maneuverability, highlighting the trade-offs between simplicity and control complexity. Having a vectored thruster arrangement allows for more maneuverability with a smaller form factor. It is seen in figure 2, that the orientation of the upward facing thrusters can significantly impact the vehicles ability to roll and pitch efficiently. This makes the amount and orientation of thrusters a key consideration as the goal for the QUT demonstration ROV is to have a small form factor, while still being able to perform complex maneuvers.



Scheme	Num	Roll	Pitch	Advantages	Disadvantages
	5	✗	✗	Minimum number of thrusters	Underactuated Low maneuver capability Balancing problems Only one motor for the vertical thrust Central motor reduces payloads space
	6	✗	✓	Limited number of thrusters Good components disposition	Underactuated Critical balancing of roll DOF especially in the open configuration
	6	✓	✗	Limited number of thrusters Good components disposition	Underactuated Critical balancing of pitch DOF
	7	✓	✓	Minimum number of thrusters to control 6 DOFs	Asymmetrical configuration (not suitable for torpedo shape)
	8	✓	✓	Completely symmetrical 6 DOFs completely controlled	More thrusters than necessary

Figure 2: Comparison of different thruster orientations and their impact on maneuverability.[20]

2.3.2 Material Selection and Waterproofing

Material selection directly impacts the vehicle's weight, durability, and operational depth. For low-cost educational platforms like the ArduinoSub and the vehicle proposed by Anwar et al. [5], PVC and acrylic are common choices due to their affordability and ease of fabrication. For more robust applications, designs progress towards aluminium frames and hulls [8, 22], with high-performance vehicles intended for deep-sea operation employing materials like carbon fibre and syntactic foam to achieve high strength-to-weight ratios [15].

Waterproofing remains a critical and persistent challenge. Standard solutions include O-ring seals for static enclosures and potted cable penetrators [18]. However, the literature presents several innovative approaches to overcome the limitations of these methods. The Jeff Autonomous Underwater Vehicle (AUV) uses a novel non-penetrative magnetic coupling to transmit torque from internal motors to external propellers, completely eliminating the need for a dynamic shaft seal [19]. The design by Tang et al. [23] also highlights custom-developed connectors as a significant improvement over permanently potting electronics, allowing for easier maintenance and repair.

For the QUT demonstration ROV, waterproofing will be a key challenge due to its small form factor. The best method seen in multiple designs is the use of a water tight acrylic enclosure with O-ring seals on the ends. This allows for electronics to be bundled and waterproofed in a single enclosure, with waterproof connections to thrusters and sensors. The next key consideration is ensuring all electronics like sensors, thrusters and electronic speed controllers are waterproofed, as these are exposed and vulnerable to water damage. Conclusive and reliable testing of the waterproofing techniques will be required before any ROV design is submerged in water.

2.3.3 Hardware Selections

Propulsion and Sensing. The choice of thrusters and sensors is dictated by the vehicle's mission profile and budget. Propulsion systems range from modified low-cost(\$50) bilge pumps in budget designs [21] to commercially available, high-performance brushless DC thrusters like the BlueRobotics T200(\$350 per unit), which are noted for their power and reliability [7, 12]. Sensor suites vary significantly; educational kits may only include a basic Inertial Measurement Unit (IMU) and a camera [25], while advanced research platforms like EVA and Mesobot are equipped with a comprehensive array of high end high-cost sensors, including Doppler Velocity Logs (DVLs) for measuring velocity relative to the seafloor($12,500), USBL positioning systems for underwater localization($3000), and high-resolution waterproofed cameras for visual navigation($300) [17, 28].

Control Hardware. The selection of onboard electronics reflects a trade-off between cost, computational power, and development complexity. At the low-cost end of the spectrum, microcontroller based systems are prevalent. The D20-ROV and ArduinoSub, for instance, use an Arduino Mega 2560 as the central brain, which is sufficient for basic manual control and sensor interfacing [4, 27]. For more advanced capabilities, single-board computers like the Raspberry Pi are frequently adopted, as seen in the BlueRov2 and PolROV designs, providing a Linux-based environment capable of handling networking, video streaming, and more complex algorithms [12, 13]. High-performance vehicles designed for significant autonomy, such as EVA and Mesobot, employ multi-computer architectures with powerful CPUs and dedicated GPUs (e.g., Nvidia Jetson TX2) to process large volumes of sensor data in real-time [17, 28].

ML and object recognition capabilities are becoming less resource intensive as algorithms improve, however powerful hardware is still required to run these algorithms. This becomes quite a key consideration as a powerful computer is now required on the small ROV. This sets design requirements like minimum size, power and cooling requirements, along with the need for a robust software stack to run the ML algorithms.

2.3.4 Software and Communication Frameworks

The software stack and communication architecture are integral to the ROV's functionality. For complex, modular systems, the Robot Operating System (ROS) is the framework of choice, as seen in the Autonomous ROV for Marine Growth and the EVA hybrid vehicle [16, 17]. ROS is valued for its extensive libraries, hardware drivers, and robust inter-process communication, which significantly accelerates development time. On simpler platforms, custom firmware is often developed in C++ within the Arduino IDE or using Python on a Raspberry Pi [25]. Open-source firmware like ArduSub, used in the VITA1 prototype, provides a powerful and well-supported alternative to developing a control system from scratch [11].

Communication is almost universally handled via a physical tether for ROVs, which provides both power and a high-bandwidth data link. This link is typically Ethernet over twisted pairs, though high-end systems may use fibre optics for greater bandwidth and distance [15]. Hybrid AUV/ROV systems like EVA and Mesobot feature multiple communication methods, including acoustic modems for low-bandwidth untethered command and control, and Wi-Fi or RF links for high-speed data transfer when surfaced [17, 28]. For this project, leveraging an existing framework like ROS or ArduSub could significantly reduce development time and increase reliability, as these frameworks come with extensive documentation and community support. However, a custom software stack based in a language like python may be necessary to meet specific project requirements or to optimize performance for the unique hardware configuration like acoustic communication or sensor integration. For smaller scale ROVs, a lightweight framework or even a bare-metal approach may be more appropriate to minimize resource usage and complexity.

2.3.5 Control System Architectures

Control strategies for underwater vehicles have matured from direct teleoperation to sophisticated autonomous behaviours [27]. The foundational control method discussed in much of the literature is the Proportional-Integral-Derivative (PID) controller, used for fundamental tasks like depth-hold and headinghold in vehicles such as the PolROV and Ariana-I [13, 18]. These controllers are well-understood and relatively simple to implement. However, due to the highly non-linear dynamics of underwater vehicles, more advanced techniques are often required for robust performance, especially in the presence of external disturbances like currents [27]. To address this, some designs implement Sliding Mode Control (SMC) for its robustness to parameter uncertainties [27], or Fuzzy Logic controllers which do not require a precise mathematical model of the system [10]. The Kambara AUV represents the cutting edge, employing model-free reinforcement learning to allow the controller to learn the vehicle's dynamics through trial and error, avoiding the need for an explicit model altogether [26].

2.3.6 System Modelling Approaches

The development of a control system is often preceded by system modelling to simulate and predict the vehicle's behaviour. A key distinction in the literature is the approach taken to derive this model. Many research-grade projects, such as the eROV and the spherical AUV by Zavari et al. [30], develop a comprehensive 6-DOF dynamic model from first principles. This process involves using Computer-Aided Design (CAD) software to determine rigid-body parameters (mass, inertia) and Computational Fluid Dynamics (CFD) simulations to estimate hydrodynamic coefficients (drag, added mass) [7, 12]. This model-based design allows for extensive simulation and controller tuning before physical construction. An alternative, empirical approach is system identification, where experimental data from a physical prototype is used to derive a transfer function model. This was successfully demonstrated by Aras et al. [6] for the UTERG-ROV2, providing an accurate model for depth control without complex theoretical analysis. The choice of modelling approach represents a trade-off between theoretical rigour and the practicalities of physical testing.

2.4 Conclusion

The review of existing ROV designs highlights a clear and consistent set of themes and trade-offs. Design choices regarding chassis, materials, and thruster configuration are heavily influenced by the vehicle's intended mission, balancing modularity against hydrodynamic efficiency. The selection of hardware and software follows a similar pattern, scaling from simple microcontrollers for educational kits to powerful, networked computers for autonomous research platforms. The literature demonstrates that while numerous solutions exist for large-scale or highly specialised vehicles, there remains a significant gap for a small-scale, low cost platform that is both modular and computationally equipped for modern ML research. The findings from this review directly inform the proposed methodology for this project.

3 Stakeholders & Resources

3.1 Stakeholders

The stakeholders for this project are identified in the table below. Regular updates will be provided to the supervisor, with final outcomes presented to the QUT engineering faculty.

3.2 Resources

Successful completion of this project requires the following resources:

- **Lab Access:** Access to QUT's electronics and fabrication labs for assembly and testing.

Table 1: Project Stakeholders

Stakeholder	Interest / Role
Project Supervisor	Provides technical guidance, assesses progress, ensures academic rigour.
QUT Faculty of Engineering	End-user of the ROV for demonstrations and future student projects.
Future EGH400 Students	Potential users of the ROV as a platform for software/control projects.
Technical Staff	Provide access to workshops and advice on fabrication.

- **Funding:** A project budget for purchasing components (thrusters, sensors, electronics, frame materials).
- **Software:** MATLAB/Simulink for control system modelling, and Python for ML pipeline development.
- **Testing Facilities:** A water tank or pool for vehicle testing and validation.
- **Existing Hardware:** A standard BlueROV2 for benchmarking and scale comparison.

4 Project Methodology

The project will follow a systems engineering approach, beginning with a detailed design phase informed by the literature review, followed by iterative prototyping and testing.

4.1 Design Choices

The mechanical and electrical design will focus on modularity and miniaturisation. Key decisions will involve:

- **Frame and Materials:** After reviewing existing designs, a mix of a open chassis for mounting sensors and thrusters, and a waterproofed acrylic enclosure for electronics will be selected. the material used for the open chassis will be aluminum item [3], due to its strength and light weight, while the acrylic enclosure will picked from BlueRobotics's section of enclosures[1]. To ensure the correct size and weight for slightly positive buoyancy, current designs use buoyancy foam. This approach will also be used with 3D printed dichtol[2] coated PLA mounts for foam, thruster and sensor mounting. A area below the ROV will be left for a general mount solution for future sensors and payloads.
- **Autopilot:** To interface with Thrusters and any additional standard sensors, a Pixhawk 6 will be used. This small device will allow for thruster configuration and contains a IMU for orientation data and barometer for depth control. The Pixhawk 6 will run PX4 which is a open source autopilot software that will allow for easy integration with the Graphical User Interface (GUI) and ML pipelines. This will simplify the control system development and allow for future users to work with industry standard software.
- **Computing:** The companion computer to communicate with ground stations, process image data and run path finding algorithms will be a pi 5. This is the latest Raspberry Pi model and has enough processing power to run a basic ML pipeline for object detection and classification. The Pi 5 also has

well documented support for PX4 communication and the possibility to run ROS2 for future control methods.

- **Additional hardware:** Additional hardware includes batteries for 1 hour operation time, a raspberry pi camera module 3 for image data, a power management board to control power, a kill switch for safety, A light for the camera to ensure viability, a module like fathom-x [1] for wired communication and a audio based module for wireless communication.

- **Thrusters:** The choice of thruster will be the widely used BlueRobotics T200 thrusters[1]. These are a well documented and widely used thruster that will allow for easy integration with the Pixhawk 6. The T200 thrusters are also waterproofed and have a good thrust to weight ratio.

4.2 Control System Development

The control system will be developed in stages:

- **PX4 Intergration and Setup:** Configure the Pixhawk 6 with the T200 thrusters and basic sensors (IMU, barometer) to establish a stable control loop for depth and orientation.

- **Sensor Integration:** Gradually integrating sensors (Audio, tether, camera, light) into the control loop to enhance stability and performance.

- **Crude Simulation:** Using MATLAB/Simulink or Engine based simulations to simulate the ROV's dynamics and validate the control system/design before physical testing.

4.3 Testing and Validation

Testing will be conducted in a controlled environment (e.g., QUT's water tank) to validate the ROV's performance against design specifications. The testing phases will include:

- **Static Tests:** Verifying waterproofing and basic electronics functionality.

- **Dynamic Tests:** Assessing maneuverability, depth control, and sensor data reliability in a controlled water environment.

- **Performance Metrics:** Collecting data on depth rating, speed, and stability to compare against design expectations.

- **Autonomy Pipeline:** Developing a basic automation routine which employs the use of ML models for object detection and classification, using the camera feed and sensor data.

5 Deliverables

The key deliverables for this project are:

1. A fully assembled and operational small scale underwater ROV.

2. A complete set of CAD drawings and electrical schematics.

3. The control system software, including a basic GUI for manual operation.

4. A set of performance metrics demonstrating the ROV's capabilities, including depth rating, maneuverability, and sensor data reliability.
5. A basic automation pipeline for ML model training and inference, including a basic dataset of sensor readings and control actions.
6. A final project report detailing the design, methodology, and results, in line with professional engineering standards.
7. Interim status reports to the project supervisor as required.

6 Quality & Sustainability

6.1 Quality

The quality of the final deliverable will be validated against a set of performance criteria:

- **Maneuverability:** The ROV must demonstrate stable control in all degrees of freedom.
- **Depth Rating:** The main electronics enclosure must remain watertight at a target depth of $10\,\mathrm{m}$.
- **Functionality:** The camera feed and all sensor data streams must be reliable and accessible via the control GUI.

Quality will be checked at each milestone through supervisor reviews and adherence to design documentation.

6.2 Sustainability

Sustainability will be considered through:

- **Life Cycle:** Designing for modularity and repairability to extend the ROV's operational life for future cohorts.
- **Materials:** Where possible, using recyclable materials like PETG for 3D-printed components.
- **Knowledge Transfer:** Producing comprehensive documentation to ensure the project's findings and design are sustainable and can be built upon in the future.

7 Risks, Requirements & Constraints

7.1 Constraints

- **Time:** The project must be completed within the 280-hour allocation for EGH400.
- **Safety:** All work must comply with QUT's lab safety policies and procedures.
- **Testing Area:** The testing area required for the final product is large(pool or aquarium) and will need to be sourced and used safely.

7.2 Risks

The following key risks have been identified. Mitigation strategies will be actively managed. A risk assessment has been completed for use of laboratories/workshops and future testing in water.

Table 2: Project Risk Assessment

Risk	Likelihood & Consequence	Mitigation Strategy
Waterproofing Failure	High likelihood, High consequence (equipment damage)	Iterative pressure testing of all enclosures before full system integration. Use of redundant seals.
Component Delays	Medium likelihood, Medium consequence (timeline impact)	Order critical components early. Identify alternative suppliers for key parts like thrusters and sensors.
Software Integration	High likelihood, Medium consequence (timeline impact)	Develop and test software modules independently before integration. Use version control (Git).
High Speed Prop Safety	Medium likelihood, High consequence (injury)	Implement safety guards around propellers. Ensure there is a clear risk assessment in place and there is a exclusion zone when tests occur. Use low-voltage, low-current thrusters to minimize risk.
Electronic Safety and Use	Low-Medium likelihood, High consequence (injury)	Ensure all electronics are properly insulated and waterproofed.Ensure safety equipment is used when soldering and batteries are stored and used inline with the consumer guidelines. Follow QUT's lab safety policies.

8 Timeline & Deliverables

The project is scheduled over two semesters (EGH400-1 and EGH400-2), totalling approximately 280 hours.

Milestone	Focus	Deliverable(s)	Due Date
1	Literature Review & Planning	Project Proposal (this document)	Week 7
2	Conceptual & Detailed Design	Complete CAD models, electrical schematics, bill of materials	Week 10
3	Component Procurement	All essential hardware ordered and received	Week 11-12

Continued on next page

Table 3 – continued from previous page

Milestone	Focus	Deliverable(s)	Due Date
4	Electronics Integration	Electronics installed and basic power-on tests completed	Week 12-Sem1,Week 1
5	Frame & Enclosure Assembly	Assembled mechanical frame and waterproofed enclosures	Semester 1, Week 4-5
6	Software & Control System	Basic manual control software functional	Semester 2, Week 5-9
7	System Testing & Validation	Full system wet-testing, performance validation	Semester 2, Week 9-12
8	Final Reporting	Draft Final Report, Final Report, Oral Presentation	Semester 2, Wk 12-13

9 Management of Project Changes

Any requested changes to the project scope by the supervisor or other stakeholders will be formally managed. A change request will be documented, outlining the nature of the change, its impact on the timeline and resources, and the reason for the change. This document will be reviewed with the supervisor before any new work is undertaken. This scope of work will be updated to reflect any approved changes, and version control will be maintained.

10 Sign off

By signing below, the Student Engineer agrees to undertake the project as outlined in this Scope of Work.

STUDENT ENGINEER	**DATE**

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