

AFRICAN SCHOOL OF INNOVATION SCIENCE AND TECHNOLOGY (ASIST)



TEAM
HYDRO
SAPIENS

ROV TECHINICAL
REPORT
2026 SEASON

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Table of Contents

Abstract 2

Abstract.....3

Project Management.....3

 Team Member Roles.....3

 Work Plan.....4

Engineering Design Rationale.....4

 Step-by-Step Planning.....4

 Decision and Balanced Trade-offs.....5

Innovation.....6

Problem Solving.....6

Systems Approach.....7

 Vehicle Structure.....7

 Vehicle Systems.....7

 Electrical/Control Systems.....7

 Tether Management.....7

 Propulsion.....7

 Buoyancy and Ballast.....7

 Payload and Tools.....8

Safety and Testing.....8

Abstract

This technical report documents the design, development, and testing of a Remotely Operated Vehicle (ROV) for the 2026 MATE ROV Competition. The vehicle is designed to perform a series of complex underwater tasks, including object manipulation, valve turning, and sample collection. The design prioritizes a modular, cost-effective, and robust architecture, utilizing readily available materials such as PVC and foam, combined with a custom hydraulic manipulator system. Key engineering principles, including Archimedes' Principle for buoyancy and Pascal's Principle for the hydraulic system, form the foundation of the vehicle's design. The report details the project management structure, engineering design rationale, systematic planning, and rigorous safety and testing methodologies employed throughout the development lifecycle.

Project Management

Team Member Roles

Team Member	Role	Responsibilities
Lowena Mwinja	Project Manager & Electrical Lead	Oversee project timeline, budget, and team coordination; design and integrate all electrical and control systems.

Linda Katusiime Praise	Mechanical Lead	Lead the structural design, fabrication of the frame, and integration of the propulsion system.
Linda Katusiime Praise	Software & Controls Engineer	Develop and implement control algorithms, manage the Arduino and Sabertooth driver interfaces, and pilot the ROV.
Shadrach Ofwono	Hydraulics & Payload Specialist	Design and build the custom hydraulic manipulator system and develop the mission-specific payload tools.
Laurean Rugyendo	Safety Officer & Tether Manager	Enforce all safety protocols, design and manage the tether system, and lead testing and troubleshooting.

Work Plan

Phase	Week	Tasks	Deliverable
Concept & Design	1-3	Review competition rules, brainstorm design concepts, create initial CAD models, and select materials.	Design Specification Document
Component Procurement	3-4	Order all electronic components, PVC pipes, fittings, and raw materials for the hydraulic system.	All materials received and inventoried.
Frame Fabrication	5-7	Cut, assemble, and seal the PVC frame; mount thrusters and install buoyancy foam.	Completed ROV chassis.
Electrical & Control System	7-10	Assemble electronics enclosure, wire Sabertooth drivers, program ESP32-CAM and Arduino, and test basic motor functions.	Operational control system.
Hydraulic System	10-13	Fabricate and assemble the hydraulic manipulator, syringe actuators, and piston mechanism; test the hydraulic circuit.	Functional hydraulic arm.
Integration & Testing	13-15	Integrate the hydraulic system with the electrical controls, test in a pool environment, and debug all systems.	Fully integrated and dry-tested ROV.
Mission Simulation & Refinement	15-16	Practice mission tasks, refine pilot controls, and perform final weight and buoyancy adjustments.	Mission-ready ROV.

Engineering Design Rationale

Step-by-Step Planning

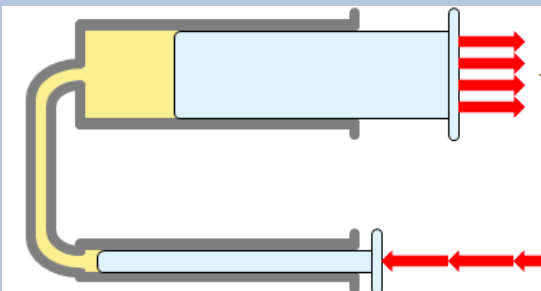
The design process followed a structured, iterative approach. The team first decomposed the mission tasks into primary functions: stable underwater flight, precise manipulation, and reliable video feedback. A functional decomposition was performed to identify the critical subsystems: frame structure, propulsion, buoyancy, electrical/control, and payload tools.



The frame was designed as a modular PVC skeleton. This material was chosen for its low cost, ease of machining, high strength-to-weight ratio, and corrosion resistance in saltwater. The rectangular shape provides inherent structural stability and a large, open central bay for mounting components. This layout allows for a low center of mass and a high center of buoyancy, enhancing passive stability as per Archimedes' Principle.

A custom hydraulic manipulator was developed to meet the requirement for a small, lightweight, but powerful gripping mechanism.

Using Pascal's Principle, the system transmits force via an incompressible fluid (water from a syringe), allowing the main actuator to be located remotely within the electronics enclosure, reducing weight and complexity at the end-effector.



Decision and Balanced Trade-offs

Design Decision	Option A (Chosen)	Option B (Rejected)	Rationale for Choice
Frame Material	PVC Piping	Aluminum Extrusion	PVC is significantly cheaper (\$20 vs. \$80), easier to cut and modify with hand tools, and provides adequate strength. Aluminum was heavier and required specialized cutting tools.
Manipulator Actuation	Hydraulic (Syringe-based)	Electric Linear Actuator	Hydraulic solutions are lighter, cheaper (\$15 vs. \$40), and offer a fully sealed system ideal for underwater use. Electric actuators were prone to corrosion and more complex to waterproof.
Main Controller	Arduino Mega + Sabertooth 2x32	Raspberry Pi + Custom H-	The Arduino/Sabertooth combination provides a simpler, more robust solution with proven reliability for motor control. The

		Bridge	Raspberry Pi introduced unnecessary complexity, higher power draw, and greater programming overhead for a real-time control task.
Camera System	ESP32-CAM	USB Webcam via Tether	ESP32-CAM provides wireless video streaming over Wi-Fi, reducing tether wire count and complexity. A USB webcam would require a dedicated high-bandwidth data line in the tether.
Buoyancy Material	Extruded Polystyrene Foam	Syntactic Foam	Polystyrene foam is readily available and costs \$5 compared to over \$50 for syntactic foam. It provides sufficient buoyancy when properly sealed in a watertight enclosure.

Innovation

The primary innovation of this design is the custom hydraulic manipulator system. By applying Pascal's Principle, the team created a powerful, lightweight, and fully submersible gripping tool using common, inexpensive materials. The system uses a master-slave syringe configuration. Pressure applied by a servo to the master syringe inside the electronics enclosure is transmitted through a water-filled line to a slave syringe at the manipulator, which then actuates a parallel-jaw gripper. This eliminates the need for expensive, heavy, and corrosion-prone electric actuators at the end-effector, significantly reducing the ROV's overall weight and cost while maintaining high functional reliability.

Problem Solving

Several significant challenges were encountered during the development process. An early prototype of the hydraulic system suffered from leaks at the syringe-coupling interface. The team solved this by switching from standard barbed fittings to Luer-lock connectors, which provide a positive, watertight seal. Initial testing also revealed that the ROV porpoised (oscillated vertically) during forward motion. This was solved by applying the principle of vertical separation of buoyancy and mass. The center of mass was lowered by mounting the heavier battery and electronics enclosure on the bottom of the frame, while the center of buoyancy was raised by placing the foam on the top rails. This created a righting moment that dynamically stabilized the vehicle.

Systems Approach

Vehicle Structure

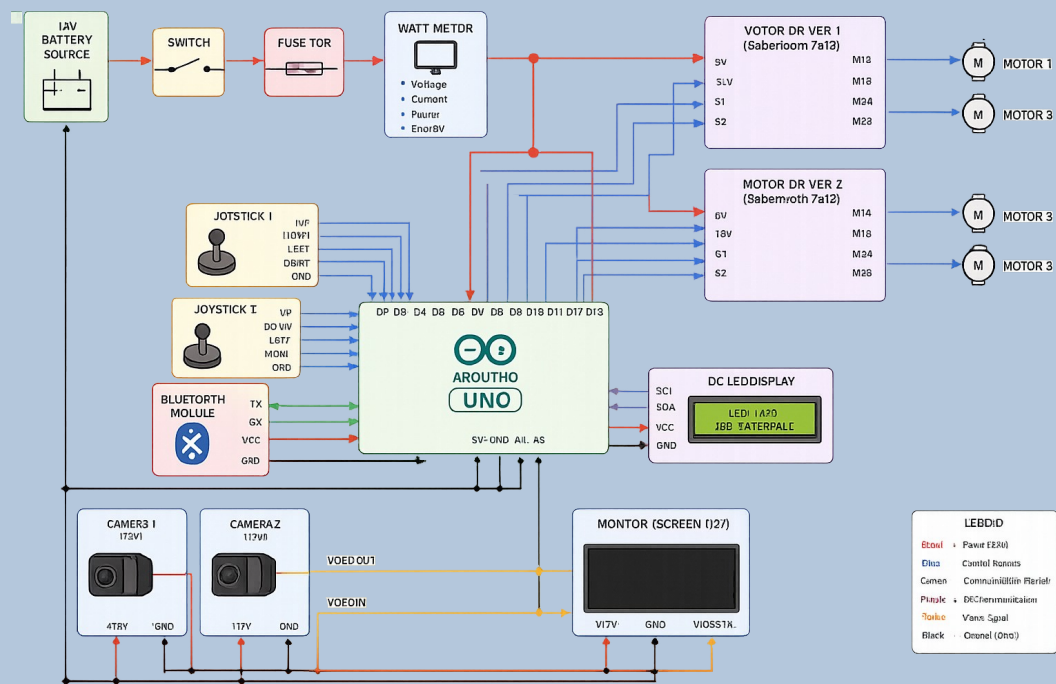
The ROV frame is constructed from **1/2-inch** schedule **40 PVC** pipe and fittings, forming a rectangular chassis. The frame is designed for a neutral to slightly positive buoyancy. All PVC

joints are welded using PVC cement to ensure structural integrity and a watertight seal. The open-frame design minimizes drag and provides excellent mounting points for all subsystems.

Vehicle Systems

Electrical/Control Systems

The electrical system is centered around an **Arduino Mega** microcontroller, which interfaces with a **Sabertooth 2x32** dual motor driver for thruster control. An **ESP32-CAM** module provides a live video feed to the surface via Wi-Fi. The system is powered by a **12V** sealed lead-acid battery housed within the central electronics enclosure. The enclosure is a waterproof PVC tube with O-ring sealed end caps, containing all sensitive electronics.



The system integrates propulsion, control, monitoring, communication, and live video streaming functions into a single electrical architecture. Power from the 12 V battery first passes through a main switch and a 10 A protection fuse before entering the watt meter, which continuously monitors voltage, current, power consumption, and energy usage of the ROV system. From the watt meter, electrical power is distributed to the motor drivers, Arduino controller, cameras, display screen, and auxiliary electronics. The use of a centralized DC power distribution system simplifies wiring and improves reliability for underwater operation.

The propulsion section consists of four DC motors controlled through two Sabertooth 2×12 motor drivers. Each Sabertooth driver independently controls two motors, enabling directional maneuvering of the ROV such as forward, reverse, turning, ascent, and descent. The motor drivers receive low-current control signals from the Arduino Uno and convert them into high-current outputs suitable for driving the propulsion motors. Each motor is rated at 2 A under full-load operation. Since there are four motors, the total propulsion current at full load is:

$$I_{\text{motors}} = 4 \times 2\text{A} = 8\text{A}$$

The Arduino Uno serves as the central processing and control unit of the system. It receives operator input signals from two joystick modules and processes these commands to generate appropriate motor control signals for the Sabertooth drivers. One joystick can be assigned for horizontal movement control while the second joystick may control vertical movement and steering functions. The Arduino also interfaces with a Bluetooth communication module, enabling wireless configuration, diagnostics, or remote command transmission when required. An I²C LCD display is connected to the Arduino for real-time monitoring and display of operational parameters such as motor status, voltage levels, and communication states.

The ROV also incorporates two underwater cameras powered directly from the 12 V supply line. These cameras provide real-time visual feedback to the operator during underwater navigation and inspection tasks. The video output from the cameras is connected directly to the onboard display screen through video input lines, allowing continuous live image streaming without the use of intermediate video transmitters or receivers. The display monitor is also powered from the same 12 V DC source, simplifying the overall power architecture of the system.

Apart from the propulsion motors, the remaining electronic loads including the Arduino Uno, Bluetooth module, LCD display, cameras, and monitor collectively consume less than 1 A. Therefore, the estimated total full-load current of the complete ROV system is:

$$I_{\text{total}} = I_{\text{motors}} + I_{\text{auxiliary}} \quad I_{\text{total}} = 8\text{ A} + 1\text{ A} \quad I_{\text{total}} \approx 9\text{ A}$$

This means the ROV system is expected to draw approximately 9 A under maximum operating conditions.

Load Current Summary

Component	Quantity	Current per Unit	Total Current
DC Motors	4	2 A	8 A
Arduino + Sensors + Display + Cameras	—	< 1 A	< 1 A
Total Full Load Current	—	—	≈ 9 A

The selection of a 10 A fuse in the main power line is appropriate because it provides overload protection slightly above the expected maximum operating current while still protecting the circuit components and wiring from excessive current during fault conditions. The overall design provides a compact, efficient, and reliable control system suitable for underwater robotic applications such as inspection, exploration, surveillance, and research operations.

Tether Management

The tether is a composite cable containing power lines, signal wires (for the Sabertooth driver and servo), and the control line for the hydraulic pump. The tether is a neutral-buoyancy assembly, constructed from a durable, abrasion-resistant jacket and marked at regular intervals for depth estimation. A strain relief is used at the ROV connection point to prevent damage to internal connectors.

Propulsion System

The propulsion system is one of the most critical subsystems of the underwater Remotely Operated Vehicle (ROV), as it provides the thrust required for movement, positioning, stability, and maneuverability underwater. In this design, the ROV uses four bilge pump motors that have been modified and converted into underwater thrusters. Bilge pump motors are commonly used in small and medium-sized ROVs because they are inexpensive, compact, waterproof, and capable of producing sufficient thrust for underwater navigation.

Thruster Configuration

The four thrusters are arranged strategically to provide movement in multiple directions. Two thrusters are mounted horizontally on opposite sides of the ROV frame, while the remaining two are mounted vertically.

Horizontal Thrusters

The two horizontal thrusters are responsible for:

- Forward movement
- Reverse movement
- Turning (yaw control)
- Lateral maneuvering and steering



When both horizontal thrusters rotate in the same direction and at the same speed, the ROV moves either forward or backward depending on motor polarity. When one thruster rotates faster than the other, or when they rotate in opposite directions, the ROV turns left or right. This differential thrust principle provides smooth steering control without requiring rudders or mechanical steering systems.

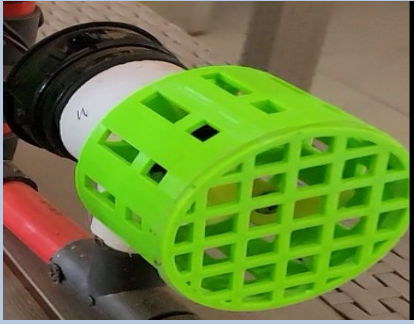
Motor Driver Control

Each pair of thrusters is controlled using Sabertooth 2×12 motor drivers. These drivers are capable of supplying bidirectional current to the DC motors, allowing precise speed and directional control. The motor drivers receive low-current control signals from the Arduino Uno and amplify them into high-current outputs suitable for operating the thrusters.

The motor drivers provide several advantages:

- Bidirectional motor control
- Smooth acceleration and deceleration
- Variable speed operation
- Protection against overcurrent and overheating
- Efficient PWM-based motor control

The Arduino processes joystick inputs from the operator and sends corresponding control signals to the motor drivers. This arrangement allows intuitive real-time navigation of the ROV underwater.



Propeller Shrouding

Each propeller is enclosed inside a shroud or protective duct. The shroud serves several important purposes:

Safety

The rotating propellers can be dangerous during handling or maintenance. The shroud protects operators and prevents accidental contact with the blades.

Improved Efficiency

The shroud helps direct water flow more effectively through the propeller, reducing turbulence and improving thrust efficiency. This increases propulsion effectiveness while reducing energy losses.

Protection Against Debris

Underwater environments often contain debris, weeds, and small particles. The shroud minimizes the risk of foreign objects entering the propeller blades and causing mechanical damage.

Buoyancy and Ballast

The buoyancy and ballast system is an essential part of the underwater Remotely Operated Vehicle (ROV) because it determines the vehicle's ability to float, sink, and maintain stable underwater positioning. A properly balanced ROV should achieve **neutral buoyancy**, meaning that the weight of the ROV is approximately equal to the weight of the water it displaces. When neutral buoyancy is achieved, the ROV neither sinks rapidly nor floats uncontrollably, allowing smooth movement and reduced power consumption during underwater operation.



In this ROV design, buoyancy is provided using blocks of **extruded polystyrene foam (XPS foam)** mounted on the upper section of the frame. Extruded polystyrene foam is commonly used in underwater robotics because it is lightweight, waterproof, corrosion-resistant, and capable of displacing a large volume of water relative to its own weight. The foam blocks are positioned on the upper side of the ROV frame so that the center of buoyancy remains above the center of gravity, improving underwater stability and helping the vehicle maintain an upright orientation.

The buoyancy calculations are based on **Archimedes' Principle**, which states:

An object fully or partially immersed in a fluid experiences an upward buoyant force equal to the weight of the fluid displaced.

The buoyant force can be calculated using:

$$F_b = \rho g V$$

Payload and Tools

The primary payload tool is the hydraulic manipulator. In addition, the ROV is equipped with a simple manipulator arm for grasping smaller objects. A custom-built panel for turning valves and a magnetic tool for retrieving ferrous objects are also carried. All tools are designed for quick-attachment to the main frame via a mounting plate.

Safety and Testing

A rigorous safety protocol was implemented throughout the project. All team members were required to wear safety glasses when cutting or machining materials. A lockout/tagout procedure was followed for all electrical work. The hydraulic system was initially pressure-tested with air to check for leaks before filling with water.

The testing methodology was phased. First, a dry test was conducted on all electrical systems



to verify functionality and ensure no short circuits. Second, a shallow water test (**0.5 meters**) was performed to check for leaks in the electronics enclosure and hydraulic lines. Third, a full depth test in a swimming pool was conducted to verify propulsion, control stability, and camera function. Final testing involved a complete mission simulation, including all required tasks, with a focus on pilot proficiency and system reliability. All test results were documented in a logbook, and any issues were addressed before the next test phase.

User Guide for the Underwater ROV System

This Remotely Operated Vehicle (ROV) is designed for underwater inspection, observation, and exploration in swimming pools, tanks, lakes, and other calm water environments. The system consists of the underwater robot unit, propulsion thrusters, onboard cameras, tether cable, and the

Barracuda control box, which contains the control electronics, display interface, and operator joysticks. Proper setup and operation are important to ensure safe usage, reliable communication, and stable underwater performance.

Before operating the ROV, carefully inspect the entire system. Ensure that all mechanical parts are securely mounted and that no wires, connectors, or thrusters are loose. Pay special attention to the tether cable, camera connections, and motor wiring because loose connections may result in signal loss, unstable movement, or equipment damage during underwater operation. Verify that all waterproof seals and cable entry points are intact to prevent water leakage into sensitive electrical components.

After inspection, connect the tether cable from the ROV to the Barracuda control box. The tether cable provides power, control signals, and camera communication between the operator and the underwater robot. Once connected, tighten the stress-relief nut firmly to prevent accidental disconnection or cable strain during operation. Next, connect the camera video connector to the designated camera slot on the control box and ensure the connection is secure. The camera power pins should then be connected to the camera power supply terminals while observing the correct polarity of the wiring.

The system operates from a 12 V DC power supply. Connect the power cable from the 12 V supply to the Barracuda control box while ensuring that the positive and negative terminals are connected correctly. Incorrect polarity may damage the electronics and motor drivers. Once all connections are complete, gently lower the ROV into the water. The ROV should preferably be operated in calm or non-moving water during initial testing and training to ensure stable maneuverability and easier control.

After placing the ROV in the water, switch on the 12 V power supply followed by the main power switch located at the rear side of the Barracuda control box. Once powered, the system status LED should illuminate green, indicating that the control system is active and functioning correctly. The onboard display screen should also show the live video feed from the underwater cameras. The operator should stand directly in front of the control box while maintaining a clear view of the display screen and joystick controls.

The ROV movement is controlled using two joysticks mounted on the control panel. The left joystick controls horizontal movement and turning operations. To move the ROV forward, gently push the left joystick upward, away from the operator's position. To reverse the ROV, slowly pull the left joystick downward toward the operator. Turning movement is achieved by moving the same joystick sideways. Pushing the left joystick to the right causes the ROV to rotate or turn right, while pushing it to the left rotates the ROV toward the left side. Smooth and gradual joystick movements are recommended to maintain stability underwater and prevent sudden directional changes.

The right joystick controls vertical movement and depth positioning. To descend deeper into the water, gently pull the right joystick downward toward the operator. To raise the ROV upward toward the surface, slowly push the right joystick upward away from the operator. The vertical thrusters will respond proportionally to joystick movement, allowing precise depth control and stable underwater hovering.

During operation, the operator should continuously monitor the live video feed displayed on the screen. The cameras provide real-time underwater visibility for navigation, inspection, and obstacle avoidance. Avoid operating the ROV near sharp objects, heavy currents, or debris that may damage

the thrusters or tether cable. If unstable movement, unusual noise, overheating, or signal interruption occurs, immediately switch off the system and inspect all electrical and mechanical connections before continuing operation.

After completing the underwater mission, slowly retrieve the ROV from the water while avoiding excessive pulling force on the tether cable. Switch off the control box power switch before disconnecting the 12 V power supply. Disconnect all camera and tether connections carefully, then rinse the ROV with clean fresh water if it was operated in dirty or salty water. Allow all components to dry properly before storage to prevent corrosion and prolong equipment lifespan.

Proper handling, regular inspection, and careful operation of the ROV system will ensure reliable performance, longer service life, and safe underwater exploration.

1. Mechanical Structure and Frame

The frame forms the main structural body of the ROV and supports all electrical and mechanical components. PVC material is selected because it is lightweight, corrosion-resistant, inexpensive, and easy to fabricate.

Item	Quantity	Unit Cost (USD)	Total Cost (USD)
PVC Pipes and Fittings	1 Set	70	70
Fasteners, Clamps, Brackets	1 Set	35	35
Waterproof Sealants and Adhesives	1 Set	25	25
Protective Thruster Shrouds	4	12	48
Subtotal			178

2. Propulsion System

The propulsion system uses modified bilge pump motors converted into underwater thrusters. Four thrusters provide full underwater maneuverability.

Item	Quantity	Unit Cost (USD)	Total Cost (USD)
Bilge Pump Motors	4	35	140
Marine Propellers	4	15	60
Motor Waterproofing Materials	1 Set	40	40
Sabertooth 2×12 Motor Drivers	2	125	250
Subtotal			490

3. Control and Electronics System

The control system handles motor control, joystick interfacing, communication, and monitoring.

Item	Quantity	Unit Cost (USD)	Total Cost (USD)
Arduino Uno	1	20	20
Joystick Modules	2	10	20

Item	Quantity	Unit Cost (USD)	Total Cost (USD)
Bluetooth Module	1	12	12
I2C LCD Display	1	15	15
Main Power Switches	2	8	16
Fuse Holder and 10A Fuse	1	10	10
Watt Meter	1	25	25
Wiring and Connectors	1 Set	45	45
Waterproof Electrical Connectors	1 Set	40	40
Subtotal			203

4. Camera and Video Monitoring System

The ROV includes two underwater cameras connected directly to the display screen for live video streaming.

Item	Quantity	Unit Cost (USD)	Total Cost (USD)
Waterproof Underwater Cameras	2	60	120
12 V LCD Monitor/Screen	1	110	110
Video Cables and Adapters	1 Set	30	30
Camera Mounting Accessories	1 Set	20	20
Subtotal			280

5. Power System

The power subsystem supplies electrical energy to all propulsion and electronic components.

Item	Quantity	Unit Cost (USD)	Total Cost (USD)
12 V Deep Cycle Battery	1	120	120
12 V Battery Charger	1	45	45
DC Voltage Regulators	2	15	30
Power Distribution Components	1 Set	25	25
Subtotal			220

6. Buoyancy and Ballast System

The buoyancy system ensures neutral flotation and underwater stability.

Item	Quantity	Unit Cost (USD)	Total Cost (USD)
Extruded Polystyrene Foam Blocks	1 Set	35	35
PVC Ballast Tubes	2	12	24
Lead Shot Ballast Material	1 Set	20	20
Mounting Hardware	1 Set	10	10
Subtotal			89

7. Tether and Control Box

The tether and control box provide communication and operator interface functionality.

Item	Quantity	Unit Cost (USD)	Total Cost (USD)
Multi-Core Tether Cable	20 m	4/m	80
Barracuda Control Box Enclosure	1	60	60
Cable Stress Relief Components	1 Set	15	15
Cooling and Ventilation Accessories	1 Set	20	20
Subtotal			175

Total Estimated Budget

Section	Cost (USD)
Mechanical Structure	178
Propulsion System	490
Control and Electronics	203
Camera and Video System	280
Power System	220
Buoyancy and Ballast	89
Tether and Control Box	175
Grand Total	1,535 USD