A Collection of ROV Design Summaries

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Contents

REMOTELY OPERATED UNDERWATER VEHICLE (ROV)

Team: Jothikrishna K, Rithika S M, Swetha S V, *Kavitha K **Date:** August 14, 2025**Cite:** [K et al., 2023]

Abstract

The purpose of the Remotely Operated Vehicle (ROV) is to provide a safe and efficient method for underwater exploration and inspection, particularly in deep-sea environments. It is designed for tasks such as inspecting and maintaining underwater structures, conducting scientific research, performing search and rescue operations, and mapping underwater environments. The ROV aims to overcome the physical and physiological limitations of human divers, offering a more effective and precise solution for deep-sea dives and data collection.

1 Design Choices and Architecture

1.1 Materials

The ROV frame features sharp side edges constructed from high-density polymers. To ensure buoyancy, the design incorporates polyurethane foam, which helps the ROV float in water. The complete 3D design of the vehicle was created using Fusion 360 software.

1.2 Waterproofing and Chassis Design

The ROV is built with an open frame structure, a deliberate choice to minimize drag force during underwater movement. This design is engineered to withstand the harsh conditions of the underwater environment, including high pressure and limited visibility. While the paper shows electronics housed within enclosures, specific details on the waterproofing methods for these components are not discussed.

1.3 Propeller Location and Prop Design Choice

The propulsion system utilizes six vector thrusters. Four thrusters are positioned to provide forward/backward and lateral movement, while the remaining two control the vertical (up and down) motion. The six thrusters are mounted at a 45-degree angle. To counteract torque, three thrusters rotate clockwise, and the other three rotate counter-clockwise. Each thruster unit consists of a brushless motor with coated magnets and windings enclosed within a rotor.

2 Hardware and Software

2.1 Chosen Propeller Motors and Other Sensors

The ROV is propelled by six brushless DC motors. The vehicle is equipped with a suite of sensors to navigate and understand its environment, including depth, temperature, and pressure sensors. A camera is installed to provide a 1080p live video feed for the operator. The core of the sensor system is a Pixhawk flight controller, which uses its own internal sensors to determine the vehicle's state. The paper suggests the future addition of a passive vector SONAR sensor for enhanced underwater imaging.

2.2 Chosen Control Hardware

The central processing unit of the ROV is a Raspberry Pi single-board computer. This is connected to a Pixhawk autopilot board which handles the low-level vehicle control. Power is supplied by a lithium-polymer (LiPo) battery pack. Manual control is achieved via a joystick connected to a surface laptop. The system also includes Electronic Speed Controllers (ESCs) to drive the thrusters and servo motors for other motion-related tasks.

2.3 Chosen Interfacing Architecture

The operator controls the ROV using a joystick connected to a laptop on the surface. This laptop serves as the ground control station. Communication between the laptop and the ROV is established via a physical tether. Fathom-X Tether Interface boards manage a high-speed ethernet connection over this tether, linking the surface computer to the onboard Raspberry Pi. The Raspberry Pi then communicates internally with the Pixhawk controller, which sends commands to the motor drivers and receives data from the various sensors.

3 Control Systems and System Modeling

3.1 ROV Communication Method

The ROV communicates with the surface control station through a physical tether. This tether facilitates a high-speed ethernet data link between the operator's computer and the ROV's onboard Raspberry Pi. The connection is managed by Fathom-X Tether Interface boards, ensuring reliable data transmission for control commands and sensor feedback.

3.2 Control Architecture

The control system is based on a layered software architecture. The Raspberry Pi runs BlueOS, a software platform for IoT applications. The Pixhawk flight controller operates on ArduSub, an open-source firmware specifically designed for underwater vehicles. On the surface, the operator uses QGroundControl, a ground control station software, to monitor the ROV's status, view the live video feed, and send control commands from the joystick. The system is designed to allow for pitch, yaw, and roll movements.

3.3 System Modeling

This paper does not develop or present a specific mathematical or dynamic model for this BlueROV2 implementation. It acknowledges the complexity and cost associated with deriving a full dynamic model through hydrodynamic testing by citing other research. The focus of this work is on the design, construction, and practical application of the ROV rather than theoretical system modeling.

Micro Underwater Vehicle Hydrobatics: A Submerged Furuta Pendulum

Team: Daniel A Duecker, Axel Hackbarth, Tobias Johannink, Edwin Kreuzer, and Eugen Solowjow
Date: August 14, 2025**Cite:** [Duecker et al., 2018]

Abstract

The HippoCampus AUV is designed as a low-cost, open-source platform for monitoring environmental fields within confined fluid volumes such as large industrial tanks, nuclear storage ponds, and port basins. Its design priorities are high agility and small size to navigate tightly constrained settings. The vehicle is also intended for deployment in fleets to enhance the spatial and temporal resolution of data collection, making low hardware cost and sensor versatility key requirements. This paper demonstrates its agile dynamics by having the µAUV swing-up and stabilize a submerged Furuta pendulum.

1 Design Choices and Architecture

1.1 Materials

The vehicle's construction emphasizes cost-effectiveness, primarily using low-cost off-the-shelf components and 3D-printed parts to achieve a total hardware cost of about $600. The main structural components include a central 3D-printed base unit that connects two acrylic tubes. These tubes house the electronics and batteries. The experimental Furuta pendulum attached to the vehicle was fabricated from aluminum poles.

1.2 Waterproofing and Chassis Design

The chassis has a modular design, centered around a 3D-printed base unit that holds the thrusters and joins two acrylic tubes containing the electronics. This design allows the tube length to be adjusted, enabling a trade-off between vehicle size and its payload capacity for sensors and batteries. The standard vehicle is 35 cm long. While the brushless motors used do not require their own sealing, additional sealing is required at the interface between the base unit and the modular thruster units. For the experiments, the pendulum's potentiometer and ball bearings were sealed using off-the-shelf latex membranes.

1.3 Propeller Location and Prop Design Choice

HippoCampus features a quad-propeller design with four thruster units mounted on the central base unit. This configuration is noted as being superior to rudder-based steering for operations in confined spaces, as it allows the vehicle to turn on the spot without needing forward motion. The four propellers provide a maximum surge velocity of $1.5\ m/s$. The thruster units are designed to be modular, which simplifies maintenance by allowing entire units to be replaced easily.

2 Hardware and Software

2.1 Chosen Propeller Motors and Other Sensors

The propulsion system consists of four thruster units, each driven by a brush-less DC-motor controlled by an electronic speed controller. The baseline sensor suite for the vehicle includes a depth sensor and a localization module that uses electro-magnetic wave attenuation for accurate position tracking. For the pendulum stabilization experiment, an analog angular potentiometer was added to measure the relative angle of the pendulum pole.

2.2 Chosen Control Hardware

The vehicle's control and processing are managed by a flight controller from the Pixhawk/Pixracer family. This hardware runs the PX4-Firmware, which the development team specifically extended to support underwater operations.

2.3 Chosen Interfacing Architecture

The system architecture is modular. Sensor data is fed into an Extended Kalman Filter (EKF) for state estimation. The estimated state and attitude set points from a high-level controller or manual input are passed to the AUV Attitude Controller. This controller computes the required thrust and moment commands (u_1, u_2, u_3, u_4). A dedicated Mixer module then translates these generic commands into specific signals for each of the four motor thrusters. This abstraction allows the same control logic to be applied to different physical vehicle configurations.

3 Control Systems and System Modeling

3.1 ROV Communication Method

The HippoCampus is equipped with a 433 MHz radio module. This enables both vehicle-to-vehicle communication for swarm applications and communication with a ground control station. The link to the ground station can be maintained while the vehicle is submerged, allowing for real-time changes to mission and control parameters.

3.2 Control Architecture

The control system is adapted from a method used for agile aerial drones, modified for the underwater domain. A key feature is the computation of orientation errors directly in the special orthogonal group $SO(3)$, which avoids singularities and robustly handles large-angle maneuvers. The attitude control law is defined as $[u_2 \quad u_3 \quad u_4]^\top = -K_R e_R - K_\omega e_\omega$. This is supplemented by a PD feedback controller for depth, $u_1 = -K_P e_{Depth} - K_D \dot{z}_{SMO}$, where the depth derivative is calculated using a sliding mode observer.

3.3 System Modeling

A comprehensive nonlinear dynamic model of the µAUV is presented using North-East-Down (NED) coordinates. The vehicle's motion is described by the equation: $M\dot{\nu} + C(\nu)\nu + M_A\dot{\nu} + C_A(\nu)\nu + D_A(\nu)\nu + g(\eta) = \tau$. This model accounts for rigid-body dynamics (inertia matrix M, Coriolis matrix C), hydrodynamic loads (added mass M_A, added Coriolis C_A, and damping D_A), and hydrostatic forces (buoyancy and gravity, $g(\eta)$). The paper also details the dynamics of the submerged Furuta pendulum, incorporating the Morison equation to model the hydrodynamic forces acting on its slender poles.

MASUV-1: A Miniature Underwater Vehicle With Multidirectional Thrust Vectoring for Safe Animal Interactions

Team: Vladislav Kopman, Nicholas Cavaliere, and Maurizio Porfiri **Date:** August 14, 2025 **Cite:** [Kopman et al., 2012]

Abstract

The purpose of this project was to design and build a streamlined, low-cost, and smooth-hulled underwater vehicle, the Miniature Animal Safe Underwater Vehicle (MASUV-1), which utilizes an entirely enclosed propulsion and steering system. This design is intended to allow for safe operation in close proximity to marine mammals, facilitating animal behavior research and other scientific missions in environments populated by animals, by eliminating hazards like exposed propellers and control fins.

1 Design Choices and Architecture

1.1 Materials

The hull and hemispherical nose cone are constructed from a rigid, clear acrylic material. This choice allows for visual inspection of the internal components. The internal electronics tray is also made of acrylic, resting on an aluminum plate. For actuators and linkages, stainless steel pushrods and aluminum brackets and arms are used to provide strength and corrosion resistance. The vectoring cone has a complex composite structure, with a smooth thin-plastic inner surface for efficient water flow and an outer surface made of a fiberglass composite, finished with Bondo body filler and paint primer for a smooth hydrodynamic shape. Stainless steel grates cover the water inlets to prevent debris from entering.

1.2 Waterproofing and Chassis Design

The vehicle has a torpedo-type chassis, 70 cm long with a 12.7 cm diameter, composed of three sections: bow, mid, and stern. The bow and mid sections are waterproof compartments, while the stern section is fully floodable. Waterproofing between sections and at junctions is primarily achieved using silicone o-rings. A critical seal is made by having the bow section's tube overlap the mid section. To allow for the linear motion of the pushrods from the dry mid section to the wet stern section without leakage, specialized Caswell DES002 seals are employed.

1.3 Propeller Location and Prop Design Choice

The primary design driver was to create a vehicle safe for interaction with animals. Consequently, the propulsion system is entirely enclosed within the floodable stern section, with no external moving parts. A Seabotix SBT150 thruster is housed internally. Instead of traditional external propellers and control surfaces (like fins or rudders), the vehicle uses a custom-designed Multidirectional Thrust-Vectoring System (MTVS). This system features a vectoring cone at the rear that directs the jet of water from the internal thruster to provide both propulsion and steering. This innovative approach ensures a smooth, snag-free hull, minimizing any risk of physical harm to marine life.

2 Hardware and Software

2.1 Chosen Propeller Motors and Other Sensors

The main propulsion is generated by a Seabotix SBT150 thruster, which is driven by a Castle Creations Pegasus-35P Sport Electronic Speed Controller (ESC). The design is forward-looking, with a reserved space onboard for the future addition of a Global Positioning System (GPS) and an Inertial Measurement Unit (IMU) for autonomous navigation. For the experimental characterization of the steering system, a Parallax Memsic 2125 dual-axis accelerometer was mounted on the vectoring cone to measure its tilt angles.

2.2 Chosen Control Hardware

In its prototype stage, the vehicle is remotely operated. The control hardware consists of a Futaba 6EXP 6-Channel FM transmitter and a Futaba R168DF 8-Channel FM onboard receiver. The steering mechanism (MTVS) is actuated by two Futaba S3305 high-torque metal gear servo motors. Power is supplied by two custom-designed Nickel-Metal Hydride (NiMH) battery packs: a large 5000-mAh, 21.6-V battery for the main thruster and a smaller 2700-mAh, 7.2-V battery for the onboard electronics.

2.3 Chosen Interfacing Architecture

The operator controls the vehicle using the Futaba FM transmitter. This sends Pulse Width Modulation (PWM) command signals to the onboard receiver. The receiver then routes these signals to the appropriate components. The thruster speed is managed by the ESC based on a PWM signal, while the two servo motors receive separate PWM signals to control the orientation of the vectoring cone for steering. The rotational motion of the servo horns is translated into a linear motion through a system of stainless steel pushrods, which in turn manipulates the vectoring cone, achieving pitch and yaw control.

3 Control Systems and System Modeling

3.1 ROV Communication Method

Communication is established via a radio frequency (RF) link. An operator uses a Futaba 6EXP 6-Channel FM transmitter to send commands to the vehicle. Due to the high attenuation of radio signals in water, two antenna configurations are used: a small custom-made antenna for shallow depth runs, and a whip and buoy antenna for deeper runs. The buoy floats on the surface, ensuring the antenna remains out of the water and maintaining a stable communication link with the submerged vehicle.

3.2 Control Architecture

The vehicle is operated under direct manual control. Steering is not achieved with traditional fins but through the Multidirectional Thrust-Vectoring System (MTVS). The jet of water expelled by the internal thruster is deflected by a movable vectoring cone at the stern. This cone is manipulated by two servo motors, one controlling lateral motion (yaw) and the other controlling transverse motion (pitch). This setup allows for high maneuverability, with diving and surfacing achieved dynamically. The paper notes that future work will focus on developing closed-loop control systems for autonomous operation.

3.3 System Modeling

A detailed kinematic model of the MTVS was developed to understand its performance and limitations. The system was modeled as a four-link (4-SPS) generalized parallel manipulator, where the vectoring cone is the end-effector. The model uses Jacobian matrices to establish the relationship between the velocity of the pushrods (actuator inputs) and the resulting angular velocity of the vectoring cone (control output). This analysis was used to characterize the workspace of the MTVS and identify kinematic singularities—configurations where the system loses its ability to move in certain directions. The workspace was found to be approximately $\pm 16°$ for independent yaw or pitch and reduced to about $\pm 11°$ for combined diagonal movements. This theoretical model was validated with experiments that measured the cone's angle in response to PWM signals.

Mechatronic design of a miniature underwater robot for swarm operations

Team: S. Mintchev, E.Donati, S.Marrazza, C.Stefanini **Date:** August 14, 2025**Cite:** [Mintchev et al., 2014]

Abstract

This paper details the mechatronic design of Jeff, a miniature Autonomous Underwater Vehicle (AUV). Jeff was created for the EU-funded CoCoRo project, which is developing a cognitive swarm of affordable underwater robots to improve decision autonomy and robustness in unpredictable oceanic conditions. The AUV is designed as an affordable, miniaturized testbed for validating swarm and cognition algorithms with a large number of vehicles (30-40 AUVs). Its primary purpose is to operate in 3D cluttered environments, performing tasks such as searching for targets on the seafloor, like locating the source of pollution from leaking barrels, by leveraging the distributed sensing capabilities of the swarm. It features multi-directional perception and communication systems to support these swarm operations.

1 Design Choices and Architecture

1.1 Materials

The chassis of the Jeff AUV is a streamlined shell manufactured using rapid prototyping. For the aft propulsion system's magnetic coupling, specific materials were chosen to ensure efficiency and durability. The dry magnet housing is constructed from PEEK (Polyether ether ketone), a non-conductive material with high mechanical and thermal resistance selected to prevent the generation of braking eddy currents during magnet rotation. The small spheres that serve as contact points within this coupling are made of ceramic to reduce wear while maintaining non-conductive properties. The magnets themselves are cylindrical N35 neodymium magnets.

1.2 Waterproofing and Chassis Design

The Jeff AUV is a miniature vehicle measuring 250x120x50 mm with a weight of 970g, designed to be neutrally buoyant. Its streamlined shell is produced via rapid prototyping. Waterproofing is a key design focus, achieved without conventional seals to improve energetic efficiency. For the propeller systems, torque is transmitted from internal motors to external propellers via a magnetic coupling across a thin (0.4 mm) septum, which creates a completely waterproof barrier without mechanical penetration. For the buoyancy control system, waterproofing is achieved using rolling diaphragms. These are flexible membranes that form a continuous, almost frictionless seal between the piston and the cylinder wall, preventing water ingress as the piston moves to adjust volume. Passive stability for the roll axis is managed by tuning the internal ballast distribution to adjust the center of mass relative to the center of buoyancy.

1.3 Propeller Location and Prop Design Choice

The propulsion system is configured for high mobility in 3D space. Two aft propellers, parallel to the surge axis, provide forward thrust and yaw control. A bow thruster, oriented parallel to the sway axis, is used for steering left and right. This configuration allows the AUV to actively control surge, pitch, yaw, and heave. Propellers were chosen as the propulsion method because they are reliable, well-understood, and simpler to control compared to more complex biomimetic systems. The aft units use a 25 mm diameter propeller, while the bow thruster employs a contra-rotating propeller design. The use of a custom magnetic coupling in the propulsion design was a deliberate choice to create a system that is compact, energetically efficient, and inherently waterproof.

2 Hardware and Software

2.1 Chosen Propeller Motors and Other Sensors

The aft propulsion system is driven by two parallel **Precision Microdrives 108-104** DC motors. The bow thruster uses two **N20 DC Motors**. The buoyancy control system is actuated by a **Precision Microdrives 212-117** DC motor. The AUV is equipped with a wide range of sensors for navigation and perception. This includes a pressure sensor for depth measurement, alongside a gyroscope, accelerometer, and magnetometer for attitude and locomotion control. For local communication and sensing, the AUV uses BlueLight units (LEDs and photodiodes) and 14 electrodes for potential field communication. An onboard microphone detects acoustic signals from a floating station, and the vehicle can be expanded with payloads such as temperature sensors, chemical sensors, and a camera.

2.2 Chosen Control Hardware

The Jeff AUV is controlled by custom-designed electronic boards. The paper specifies the use of "custom electronic boards" and "control and power management PCBs" that were developed for the project. No specific off-the-shelf microcontrollers or processor models are mentioned, indicating a bespoke hardware solution tailored to the AUV's needs for swarm operation and cognitive processing.

2.3 Chosen Interfacing Architecture

The system is designed to be modular and extensible. It features an expansion connector on the shell, allowing for various sensor payloads (e.g., temperature, chemicals, camera) to be plugged in to specialize the AUV for different missions. Energy is provided by an 8-cell Li-Po battery pack with a capacity of 880 mAh. The overall architecture is built for swarm robotics, facilitating communication between individual AUVs and a central floating station, which also serves as a charging and data hub via a physical docking system.

3 Control Systems and System Modeling

3.1 ROV Communication Method

Jeff utilizes a multi-modal communication system for robust swarm interaction. For short-range (up to 1 m) communication and localization, it uses bio-inspired methods: **BlueLight units** on its six sides, which use blue LEDs and photodiodes, and a **potential field** system based on 14 electrodes. For confining the swarm's operational area, the AUV has a microphone to detect a 5 kHz acoustic "virtual fence" signal emitted by a floating station from up to 10 m away. The AUV is also equipped with two loudspeakers, whose use for communication is under investigation. For energy and data transfer, Jeff can physically connect to a submerged docking station.

3.2 Control Architecture

The control architecture is designed to support swarm cognition, where individual agents have awareness and can collaboratively balance tasks. The low-level control system actively manages surge, pitch, yaw, and heave using feedback from an IMU (gyroscope, accelerometer, magnetometer) and a pressure sensor, while roll is managed through passive stability. High-level control is based on biologically inspired motion algorithms and self-organization principles. A key autonomous capability is docking; the system uses a passive magnetic alignment mechanism, where magnets on the AUV and docking station attract and guide the robot, simplifying the control algorithms needed for the final connection.

3.3 System Modeling

System modeling was employed to design and validate key mechatronic systems. A **magnetostatic finite element analysis** was used to model the performance of the magnetic coupling in the thrusters, calculating the relationship between rotational angle, torque, and attraction force. This analysis was also used to verify the effectiveness of the magnetic stabilization system for the propeller, confirming that it produces a restoring moment to prevent unwanted pivoting. To design the docking system, the "attraction region" was estimated by **numerically calculating the AUV's trajectory** under the influence of the docking station's magnetic field. This simulation, which modeled the AUV's dynamics and treated the magnets as dipoles, was used to determine the maximum initial misalignment the passive system could correct for at various approach speeds. Finally, experimental static tests were performed to create a performance model mapping the electrical power consumption of the aft thruster to its generated thrust.

Autonomous Guidance and Control for an Underwater Robotic Vehicle

Team: Robotic Systems Laboratory, ANU **Date:** August 14, 2025**Cite:** [Wettergreen et al., 1999]

Abstract

The purpose of the Kambara AUV is to develop technologies for underwater exploration and observation. The key objectives are to enable the robot to autonomously search in regular patterns, follow fixed natural and artificial features like reefs and pipes, and track dynamic targets. These capabilities are aimed at tasks such as exploring geologic features, cataloging reefs, studying marine life, inspecting infrastructure like pipes and cables, and assisting divers. The project focuses on combining vision-based guidance with a neurocontroller trained by reinforcement learning to achieve these autonomous behaviors.

1 Design Choices and Architecture

1.1 Materials

The paper does not specify the materials used for the chassis or the watertight enclosures. It describes the chassis as an "open-frame design" but provides no detail on the specific alloys or polymers used in its construction. Similarly, the composition of the watertight enclosures is not mentioned.

1.2 Waterproofing and Chassis Design

The Kambara ROV features an open-frame chassis with dimensions of 1.2m (length) x 1.5m (width) x 0.9m (height), displacing approximately 110 liters. This frame is designed to rigidly support the thrusters and two main watertight enclosures. The upper enclosure houses the real-time computing system, proprioceptive sensors, and a pan-tilt-zoom camera. The lower enclosure contains the sealed lead-acid batteries and power distribution systems. These two enclosures are connected by a flexible coupling. Additional smaller, sealed enclosures for stereo cameras are also attached to the frame.

1.3 Propeller Location and Prop Design Choice

The ROV is equipped with five thrusters that enable control over five degrees of freedom: roll, pitch, yaw, heave, and surge. This configuration makes the vehicle underactuated, as it cannot perform direct sway (lateral) motion. The thrusters are commercially available electric trolling motors that have been modified with ducts to enhance thrust. While the exact placement is not detailed, the design provides 5-DOF maneuverability.

2 Hardware and Software

2.1 Chosen Propeller Motors and Other Sensors

Propeller Motors: The thrusters utilize commercially available brushed DC electric trolling motors, which are driven by custom-designed power amplifiers capable of providing high current.
Sensors:

- **Visual:** A primary pan-tilt-zoom camera is located in the upper enclosure, supplemented by two fixed cameras in independent sealed enclosures for stereo vision-based guidance.
- **Inertial/Proprioceptive:** The sensor suite includes a triaxial accelerometer, a triaxial rate gyro, a magnetic heading compass, and inclinometers for roll and pitch measurement.
- **Environmental:** A pressure sensor for depth measurement and a leakage sensor are also integrated.

2.2 Chosen Control Hardware

The control and processing hardware is housed in the upper watertight enclosure. It consists of a real-time computing system that includes a main and a secondary processor. This system is supported by video digitizers for the cameras and analog signal digitizers for the various proprioceptive and environmental sensors. The paper does not specify the exact models of the processors used.

2.3 Chosen Interfacing Architecture

The software is a modular architecture where independent computational processes communicate via an anonymous broadcast protocol. On-board modules include a 'Vehicle Manager' (which directs commands to other modules), 'Feature Tracker', 'Vehicle Neurocontroller', 'Thruster Controller', 'Sensor Sampler', and 'State Estimator'. This on-board system interfaces with off-board guidance modules such as an 'Operator Interface', 'Mission Planner', and 'Visualization Interface' through a 'Telemetry Router'. This architecture supports a range of operational modes from direct teleoperation to supervised and full autonomy.

3 Control Systems and System Modeling

3.1 ROV Communication Method

Internal communication between software modules is handled by an anonymous broadcast protocol. For external communication, a 'Telemetry Router' is responsible for moving vehicle state, image data, and science data to the off-board systems. The system is designed for supervised autonomy, where high-level commands are sent infrequently from an operator to guide the vehicle's on-board modules. The physical layer (e.g., fiber optic or copper tether) for this communication is not specified.

3.2 Control Architecture

The core of the control system is a 'Vehicle Neurocontroller' that implements model-free reinforcement learning, specifically a Q-learning variant called advantage learning. The aim is to avoid the need for a complex, explicit dynamic model of the vehicle. This neurocontroller learns a policy to map vehicle state and visual feature data directly to thruster force commands. These commands are then executed by individual closed-loop 'Thruster Controllers'. The overall guidance strategy is based on visual servo control, using a 'Feature Tracker' to provide real-time position data of environmental features relative to the ROV.

3.3 System Modeling

A primary philosophy of this design is to avoid reliance on traditional, complex dynamic models for vehicle control. The neurocontroller is designed to learn the vehicle dynamics through interaction with the environment (model-free reinforcement learning). However, a simplified, linear vehicle dynamic model is used within the 'State Estimator''s Kalman filter to help process sensor data and produce estimates of the vehicle's position, orientation, and velocities. The paper notes this as a "contradiction" and suggests that future work aims to reduce reliance on this model. Additionally, a thruster model is used to accurately translate the desired force commands from the neurocontroller into the required motor voltages and currents.

A Modular Design Approach for Underwater ROV: TRIDENT

Team: Mangayarkarasi.T, Harshavardhan R.G, Sujith.R, Sricharan.K **Date:** August 14, 2025**Cite:** [T et al., 2024]

Abstract

The purpose of the Trident ROV is to serve as a multi-functional and cost-efficient platform with a modular design methodology [T et al., 2024]. This allows for easy reconfiguration of components based on mission needs, catering to two primary objectives: underwater search and rescue operations for the National Disaster Response Force (NDRF) in murky waters [T et al., 2024] and the inspection of cracks and defects inside Head Race Tunnels for the Ministry of Power [T et al., 2024].

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1 Design Choices and Architecture

1.1 Materials

The paper states that the second design prototype was made to be more robust through material selection, but does not specify the exact materials used for the chassis or hull [T et al., 2024]. It does mention that the main thrusters and thrust-vectored nozzles in the first design were 3D printed [T et al., 2024].

1.2 Waterproofing and Chassis Design

The core design philosophy is modularity, where the ROV is divided into separate, changeable compartments for sensors and controllers, allowing for mission-specific adaptations [T et al., 2024]. The second prototype features a cylindrical body. The paper does not discuss the specific methods used for waterproofing the modular compartments or cable penetrations.

1.3 Propeller Location and Prop Design Choice

The design featured two distinct propeller arrangements. The initial design for the NDRF had propellers installed internally on top of the vehicle [T et al., 2024]. This arrangement pulled water from above and directed it through an L-shaped tube to thrust-vectored nozzles below, a design choice made to prevent debris and underwater plants from jamming the propellers [T et al., 2024]. The second prototype, designed for tunnel inspection, was modified to have an external propeller arrangement to meet the new operational requirements [T et al., 2024].

2 Hardware and Software

2.1 Chosen Propeller Motors and Other Sensors

For an early prototype, a 775ln DC motor connected to an LN293N Motor Driver was used [T et al., 2024]. The paper does not specify the motors used in the final version of the second prototype. It mentions that the slave controller is responsible for receiving external conditions, implying the use of various sensors, but these sensors are not listed or described in the paper [T et al., 2024].

2.2 Chosen Control Hardware

The control system evolved through the design phases. The first prototype used two Arduino controllers in a master-slave configuration [T et al., 2024]. The second, more advanced prototype incorporated a Raspberry Pi as the main controller, responsible for motor speed, executing crack detection algorithms, and data transmission [T et al., 2024]. An Arduino was retained as a secondary controller in a master-slave arrangement to collect raw data, preventing workload interference with the main processor's performance [T et al., 2024].

2.3 Chosen Interfacing Architecture

A custom user interface (UI) was developed to display mission data to the operator [T et al., 2024]. This dashboard provides a live camera feed for detection, a defect log that records the type of defect (corrosion, crack, growth), and geo-tags the location with latitude and longitude [T et al., 2024]. The UI also includes a map view for navigational reference. Detected anomalies are processed and logged into a database [T et al., 2024].

3 Control Systems and System Modeling

3.1 ROV Communication Method

The initial prototype used a Flysky 2.4GHz radio controller [T et al., 2024]. This method proved problematic underwater as the signal was easily dispersed; a float was used to extend the receiver's antenna above the water surface to maintain a connection [T et al., 2024]. To overcome this limitation, the second design phase utilized tether cables for robust communication between the operator and the ROV [T et al., 2024].

3.2 Control Architecture

A master-slave configuration is central to the control architecture. In the second design, the Raspberry Pi acts as the master processor, handling high-level tasks such as running machine learning algorithms for crack detection, controlling motor speed, and managing data transmission to the user [T et al., 2024]. The Arduino functions as the slave, collecting raw sensor data and managing the ROV's movement, thereby splitting the workload and allowing the main processor to dedicate its computational resources to demanding tasks like position control and real-time analysis [T et al., 2024].

3.3 System Modeling

This topic was not discussed in this design solution in the context of vehicle dynamics or control theory. However, the paper details the use of a machine learning model, specifically YOLOv8, for object detection. The model was trained to identify underwater objects and aquatic species in the first phase, and later retrained to also detect cracks and corrosion in Head Race Tunnels for the second phase [T et al., 2024].

Design and Development Remotely Operated Vehicle for Anode Ship Hull Inspection

Team: Ahmad Faris Ali, Mohd Rizal Arshad **Date:** August 14, 2025**Cite:** [Ali and Arshad, 2017]

Abstract

The D20-ROV is an under-actuated Remotely Operated Vehicle designed and developed specifically to perform visual inspection of sacrificial anodes on ship hulls [Ali and Arshad, 2017]. The project aimed to create a low-cost and energy-efficient ROV by using only three thrusters to achieve maneuverability, including forward, reverse, turning, and depth changes [Ali and Arshad, 2017].

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1 Design Choices and Architecture

1.1 Materials

The main body of the ROV is constructed from a polymer cylinder, chosen for its light weight and low cost [Ali and Arshad, 2017]. The door of the cylinder is made from clear, transparent acrylic to provide a viewing port for the internal camera [Ali and Arshad, 2017]. The vehicle is mounted on aluminum stands. For future development, it is suggested to add a hydrodynamic cover made from fiberglass to reduce drag [Ali and Arshad, 2017].

1.2 Waterproofing and Chassis Design

The chassis is a cylindrical body with dimensions of $0.5m \times 0.46m \times 0.22m$ [Ali and Arshad, 2017]. To protect the internal electronics and power systems from seawater, the vehicle is sealed using an O-ring placed between the main cylinder body and the clear acrylic cylinder door [Ali and Arshad, 2017]. The paper notes that the flat surface of the door contributes to drag and suggests changing it to a dome shape in future iterations for improved performance [Ali and Arshad, 2017].

1.3 Propeller Location and Prop Design Choice

The propulsion system was designed to be cost-effective and consists of only three thrusters [Ali and Arshad, 2017]. Two horizontal thrusters are mounted on the sides for forward, reverse, and turning (left/right) maneuvers. A single vertical thruster is centrally located to control depth (raise and submerge) [Ali and Arshad, 2017]. This under-actuated configuration was selected to minimize development cost and power consumption compared to more complex, multi-thruster ROVs [Ali and Arshad, 2017].

2 Hardware and Software

2.1 Chosen Propeller Motors and Other Sensors

The propulsion system uses Seabotix DC Motor thrusters [Ali and Arshad, 2017]. The ROV is equipped with a sensor suite for navigation and safety, including a Compass C100 KVH, a Gyro Sensor ADXL345 for pitch, roll, and sway feedback, a Water Leakage Sensor, a Temperature Sensor, and a Depth Sensor [Ali and Arshad, 2017]. An analog camera with auto-focus is used for visual inspection, and a laser pointer helps identify object orientation. The depth sensor was noted to have a 6-meter limit and leaked at 7 meters, with the paper recommending an upgrade to a Bar30 High-Resolution sensor for future work [Ali and Arshad, 2017].

2.2 Chosen Control Hardware

The central processing unit for the D20-ROV is an Arduino Mega 2560 [Ali and Arshad, 2017]. This main control unit is responsible for reading data from all onboard sensors and issuing commands to the thrusters and camera based on operator input [Ali and Arshad, 2017]. The system is powered by a

16VDC Lithium-Polymer battery, with two DC-DC converters stepping the voltage down to 12V and 5V for various electronic components [Ali and Arshad, 2017].

2.3 Chosen Interfacing Architecture

A Graphical User Interface (GUI) was developed using Microsoft Visual Studio and C#.Net to provide real-time data visualization and control for the operator [Ali and Arshad, 2017]. The GUI displays the live video feed from the camera and continuous readouts from the sensors, including depth, pitch, roll, heading, leak status, and voltage [Ali and Arshad, 2017]. This interface allows the operator to analyze data in real time, which would be difficult with raw data streams. The software can also log all received sensor data into .txt and .csv file formats for post-mission analysis [Ali and Arshad, 2017].

3 Control Systems and System Modeling

3.1 ROV Communication Method

The D20-ROV communicates with the surface control station via a 20-meter long Universal Serial Bus (USB 2.0) cable [Ali and Arshad, 2017]. To ensure signal integrity over this distance, a repeater is attached in the middle of the cable. The USB cable handles the transmission and reception of all data and commands between the ROV and the operator's Lenovo computer [Ali and Arshad, 2017].

3.2 Control Architecture

The control architecture is centralized around the Arduino Mega 2560, which directly manages all onboard systems based on commands received from the surface GUI via the USB tether [Ali and Arshad, 2017]. The operator uses the GUI to send commands for movement and camera control. The paper acknowledges that this is a basic open-loop system from the operator's perspective and states that for future development, a robust closed-loop control system (such as PID) should be implemented to allow the ROV to better handle disturbances like waves and currents [Ali and Arshad, 2017].

3.3 System Modeling

This topic was not discussed in this design solution. The paper explicitly states that the current ROV is able to perform simple movements but a robust control system is needed for more complex operations [Ali and Arshad, 2017]. It recommends that future work should investigate model-based control strategies, such as a PID controller, which would require the development of a mathematical model of the vehicle's dynamics to effectively control the ROV in the presence of underwater disturbances [Ali and Arshad, 2017].

Mesobot: An Autonomous Underwater Vehicle for Tracking and Sampling Midwater Targets

Team: D. R. Yoerger et al. **Date:** August 14, 2025**Cite:** [Yoerger et al., 2018]

Abstract

Mesobot is a new class of autonomous underwater vehicle designed to address the specific need of observing and tracking slow-moving targets (e.g., zooplankton, fish, particle aggregates) in the ocean's midwater zone (200m-1000m) [Yoerger et al., 2018]. It is engineered to follow these targets over a full diel (daily) cycle using a vision-based control system while being minimally intrusive. It is also equipped to collect physical water samples for biogeochemical and environmental DNA (eDNA) analysis [Yoerger et al., 2018].

1 Design Choices and Architecture

1.1 Materials

The design uses syntactic foam for buoyancy, placed high on the vehicle to ensure high static pitch and roll stability [Yoerger et al., 2018]. The paper does not specify the material used for the main frame or chassis but notes that heavy components are placed low to complement the high buoyancy placement [Yoerger et al., 2018].

1.2 Waterproofing and Chassis Design

The vehicle stands 1.5 meters tall and displaces approximately 200 kg [Yoerger et al., 2018]. The internal components are housed within a main electronics housing and COTS (Commercial Off-The-Shelf) domed housings for the cameras [Yoerger et al., 2018]. The overall design is engineered to minimize hydrodynamic, acoustic, and optical disturbances to the surrounding environment. It features a flexible payload bay to accommodate a variety of sensors and samplers, such as the Suspended Particulate Rosette (SUPR) sampler [Yoerger et al., 2018].

1.3 Propeller Location and Prop Design Choice

Mesobot is fully actuated, using a combination of thrusters and a variable buoyancy (VB) system for maneuvering and hovering [Yoerger et al., 2018]. The main thrusters for forward/aft and vertical movement are designed to be low-powered ($<$ 60 watts), slow-moving, and large in diameter, a choice made specifically to minimize hydrodynamic disturbances and enable "near-lagrangian" behavior, where the vehicle moves with the ambient water [Yoerger et al., 2018]. The VB system, which uses a piezoceramic pump, reduces the need for constant thruster use while hovering, further minimizing disturbance [Yoerger et al., 2018].

2 Hardware and Software

2.1 Chosen Propeller Motors and Other Sensors

The paper specifies that low-power, large-diameter thrusters are used but does not name a specific model [Yoerger et al., 2018]. The sensor suite is extensive: for visual tracking, it uses a stereo pair of Allied Vision G-319B monochrome cameras; for scientific imaging, a Sony UMC-SC3A color 4K video/still camera with outstanding low-light capability is used [Yoerger et al., 2018]. Illumination is provided by COTS LED units from Deep Sea Power and Light, which can emit red or white light at controllable intensities. Oceanographic sensors include a CTD, dissolved oxygen (DO) sensor, an optical triplet (fluorometers and backscatter), and PAR sensors [Yoerger et al., 2018].

2.2 Chosen Control Hardware

Mesobot leverages the computing infrastructure from MBARI's LRAUV, which includes a main computer motherboard and a load controller for interfacing with and powering all onboard devices [Yoerger et al., 2018]. For the computationally intensive task of real-time visual target tracking, the system uses a dedicated Nvidia TX2 processor [Yoerger et al., 2018]. This hardware setup includes redundant emergency controls to ensure the vehicle can return to the surface in case of major system failures [Yoerger et al., 2018].

2.3 Chosen Interfacing Architecture

The system is managed by a highly flexible mission executive written in Python, using the 'smach' state machine library [Yoerger et al., 2018]. This allows complex missions to be defined using a simple XML-like language, which is interpreted at start-up to build the state machine for the dive. This architecture enables pre-programmed sequences and adaptive operations based on sensor data or visual cues [Yoerger et al., 2018]. The system also supports human supervision via two-way acoustic communications, allowing an operator to receive status updates and amend mission parameters mid-dive [Yoerger et al., 2018].

3 Control Systems and System Modeling

3.1 ROV Communication Method

Mesobot employs a hybrid communication strategy designed for operational flexibility. A mission begins in a teleoperated mode, where a human pilot controls the vehicle through a thin, data-only fiber optic tether [Yoerger et al., 2018]. Once a target is acquired, the tether is released, and the vehicle begins its autonomous tracking phase [Yoerger et al., 2018]. During autonomous operation, it can maintain two-way acoustic communication with a surface supervisor for status updates and high-level commands [Yoerger et al., 2018].

3.2 Control Architecture

The control architecture is built around a mission executive that operates as a hierarchical state machine, capable of managing different control modes: teleoperation, autonomous target tracking, and conventional survey patterns [Yoerger et al., 2018]. It is designed to be event-driven, reacting to changes in the environment or cues from the tracking software. Internal communication between the various software modules is handled by the Lightweight Communications and Marshalling (LCM) system ([Yoerger et al., 2018]. This allows seamless hand-offs between the pilot, the target-tracking system, and the mission executive as required by the mission plan [Yoerger et al., 2018].

3.3 System Modeling

This topic was not discussed from the perspective of creating a mathematical or hydrodynamic model of the vehicle. Instead, the vehicle's control for its primary task relies on a real-time, vision-based approach. The control software, running on an Nvidia TX2, processes stereo images to compute the range and bearing to a selected target [Yoerger et al., 2018]. This information is then used to generate the necessary force and moment commands for the thrusters and variable buoyancy system to follow the target [Yoerger et al., 2018].

EVA a hybrid ROV/AUV for underwater mining operations support

Team: Alfredo Martins, José Almeida, Carlos Almeida, Bruno Matias, et al. **Date:** August 14, 2025**Cite:** "[Martins et al., 2018]"

Abstract

This paper presents EVA (Exploration VAMOS AUV), an innovative hybrid ROV/AUV system designed to support the operations of an underwater mining vehicle (MV) in flooded inland mines. Developed within the European H2020 ¡VAMOS! project, EVA operates without a tether and serves two primary functions: providing enhanced situational awareness to human operators from a different viewpoint than the MV, and generating precise, real-time 3D environmental models for mining planning and supervision. It can be operated in a wireless tele-operation mode or as a fully autonomous AUV.

1 Design Choices and Architecture

1.1 Materials

The main structural component of the vehicle is high-density polyethylene (HDPE). This material was chosen for the vehicle's open-frame design because it combines low weight with excellent corrosion resistance and flexibility in manufacturing. Syntactic foam is used to provide buoyancy. The pressure housings for the electronics are likely made of aluminum, a common choice for such applications, but this is not explicitly stated.

1.2 Waterproofing and Chassis Design

EVA features an open-frame mechanical design to allow for a high degree of configurability and modularity. This approach was chosen to accommodate a large primary sensor (Coda Octopus Echoscope 3D multibeam sonar) while keeping the vehicle's overall size (1.5m x 0.7m x 0.55m) and weight (<120kg) manageable. Waterproofing is achieved through several pressure housings:

- Two main pressure housings contain the computer systems, inertial navigation system, and communication electronics.
- A smaller pressure cylinder houses the power management system and electronic thruster controls.
- The vehicle is powered by three easily removable, pressure-tolerant LiFePo battery packs.

1.3 Propeller Location and Prop Design Choice

The vehicle is designed for full 6-DOF maneuverability and control, which is essential for controlled motion and precise positioning in the restricted spaces of a mining environment. To achieve this, it is equipped with 12 brushless motor thrusters. This configuration provides a high degree of redundancy in actuation. The exact placement of the thrusters is not detailed, but the mechanical drawing shows thrusters positioned to provide thrust in all cardinal directions (surge, sway, heave) as well as rotational control (roll, pitch, yaw).

2 Hardware and Software

2.1 Chosen Propeller Motors and Other Sensors

EVA is equipped with an advanced sensor payload for navigation and environmental perception.

- **Motors**: The vehicle uses 12 brushless motor thrusters, controlled via CANbus. The specific model is not mentioned.

- **Navigation Sensors**: A fiber optic gyro Inertial Navigation System (Applied Navigation Spatial FOG) provides acceleration and angular velocity data. This is fused with velocity data from a Doppler Velocity Log sonar (Nortek 1MHz DVL). An acoustic navigation system (USBL/SBL) and GPS (when surfaced) provide absolute positioning.
- **Perception Sensors**:
  - A **3D multibeam sonar** (Coda Octopus Echoscope) or a dual-purpose profiling/imaging multibeam sonar (Kongsberg M3) serves as the primary sensor for 3D environment modeling.
  - A custom-developed **structured light system (SLS)** consisting of smart cameras and light projectors provides high-precision 3D point clouds when water turbidity is low.
  - A mechanical scanning sector sonar is used for obstacle avoidance.

2.2 Chosen Control Hardware

The system uses a multiple-computer architecture to handle the significant data processing requirements.

- The **Main CPU** is a Xeon-based computer (ComExpress Type 6 small form factor). It is responsible for the overall vehicle control, navigation, and mission execution.
- An additional **Sonar CPU** (Intel Core i3) is used exclusively for processing the data from the high-bandwidth multibeam sonar.
- The structured light systems have their own **embedded CPUs** on the cameras for image and 3D perception processing.

2.3 Chosen Interfacing Architecture

The hardware components are interconnected using standard, high-speed communication protocols.

- **Ethernet** is the primary communication backbone, connecting all main sensors (sonars, DVL, cameras) and communication devices (WiFi, modems) to the onboard CPUs.
- The INS communicates with the main CPU via a **RS422 serial link**.
- Thruster commands are sent from the main CPU to each of the 12 speed control drivers via a **CANbus** network.
- The entire software framework is built on the **Robot Operating System (ROS)**, which runs on a Linux-based OS. ROS provides the middleware for communication between all software modules (nodes) and simplifies the integration of the complex system.

3 Control Systems and System Modeling

3.1 ROV Communication Method

EVA is designed to be highly flexible in its communication methods, with a primary goal of operating untethered.

- **Full AUV Mode**: An acoustic modem (Evologics S2CR 42/65) is used for low-bandwidth communication, allowing for telemetry updates and basic commands to be sent over long distances.
- **Wireless ROV Mode**: For high-bandwidth teleoperation, a custom-developed short-range underwater radio modem is used. It can transmit data at over 5Mb/s for up to 10m, which is sufficient for relaying real-time video and sonar data when operating near the main mining vehicle or a surface vessel.

- **Surface Communication**: An IEEE 802.11g WiFi link is used for high-speed data transfer when the vehicle is at the surface.
- **Tethered Mode**: The vehicle also has the capability to be operated as a standard cabled ROV if required.

3.2 Control Architecture

The control and navigation system is hierarchical and runs within the ROS framework.

- **Navigation**: An Extended Kalman Filter (EKF) is used for state estimation. It fuses data from the high-rate IMU (gyros, accelerometers) with lower-rate aiding data from the DVL (velocity), acoustic positioning system (absolute position), and GPS (absolute position when at surface) to produce an accurate estimate of the vehicle's position, velocity, and attitude.
- **Vehicle Control**: The control structure is hierarchical. A low-level control loop manages the vehicle's velocities, integrating a thruster allocation strategy to distribute the required forces and torques among the 12 thrusters. This velocity controller receives commands from higher-level behaviors or mission plans (in AUV mode) or directly from the human operator (in ROV mode).

3.3 System Modeling

This topic was not discussed in this design solution. The paper focuses on the system's architecture, components, and field trial results rather than the development of a mathematical or hydrodynamic model of the vehicle.

From ROVs to AUVs - Optimization and Analysis of Underwater Vehicles Design

Team: Michał Purzycki, Aleksandra Komorowska, Agnieszka Ilnicka, Jakub Papież, Emilia Szymańska **Date:** August 14, 2025**Cite:** "[Purzycki et al., 2022]"

Abstract

This paper presents a comparative analysis of the design steps of four underwater robots from the PWr Diving Crew project. It describes the evolution from simplified Remotely Operated Vehicles (ROVs) to Autonomous Underwater Vehicles (AUVs) with improved environmental perception and autonomous capabilities. The analysis focuses on mechanical properties, vehicle characteristics, and design optimization based on experience gained through successive vehicle generations (ROV2, ROV3, ROV4, and Blue Nemo).

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1 Design Choices and Architecture

1.1 Materials

The materials evolved across generations to improve durability and performance.

- **ROV2**: Featured a frame of aluminium sheets and a hull of high-density polyethylene, chosen for its chemical resistance but was found to lack mechanical durability.
- **ROV3**: Was upgraded to a more robust acid-resistant aluminium frame and a single-chamber carbon fibre composite body.
- **ROV4**: The structure changed to a polypropylene frame (cut with a waterjet) protecting a main aluminium cylinder hull. The cylinder ends were sealed with a polycarbonate plate (front) and an aluminium plate (back).
- **Blue Nemo**: Used a frame made from polyoxymethylene (POM) for its high machining tolerances and water resistance. Side pipe plugs were also custom-made from POM using CNC machines, which was a significant improvement over the previous 3D printed and acetonated ABS plugs that had lower tightness.

1.2 Waterproofing and Chassis Design

The design philosophy progressed from a compact, pressure-sensitive shape to a more robust and hydrodynamically efficient open-frame structure.

- **ROV2 & ROV3**: Utilized a prism shape with a trapezoidal base, which did not guarantee high endurance against pressure. Standard waterproofing techniques like O-rings and cable glands were used. For ROV3, internal electronics were potted with non-conductive epoxy resin, but this non-reversible solution was abandoned in later designs.
- **ROV4 & Blue Nemo**: Adopted a cylindrical main hull held within an external frame. This cylindrical shape offered superior mechanical strength, while gaps in the frame reduced water resistance and provided protection. Waterproofing was notably improved from ROV4 onwards by using custom debu-connectors for wire outlets, which ensured a reliable seal while allowing for easier servicing and maintenance compared to the permanently potted electronics of ROV3.

1.3 Propeller Location and Prop Design Choice

Motor layouts were progressively optimized to enhance maneuverability and achieve full holonomicity. All designs aimed for six degrees of freedom.

- **ROV2**: Employed 6 motors. Four were set in an x-shape configuration for horizontal plane movement, while two perpendicular motors controlled vertical movement (draft).
- **ROV3**: Used 7 motors, with four in a similar x-shape configuration and three dedicated to Z-axis movement. Both ROV2 and ROV3 experienced some difficulty with rotation due to high moments of inertia.
- **ROV4**: Switched to a layout where four horizontal motors were mounted at a 45-degree angle to the longitudinal axis, allowing for full forward, backward, and sideway (strafe) movement.
- **Blue Nemo**: Used a configuration similar to ROV4, but the horizontal motors were inclined at 30 degrees. This change was justified by the vehicle's predominant forward movement profile, optimizing for forward efficiency.

2 Hardware and Software

2.1 Chosen Propeller Motors and Other Sensors

The sensor suite was expanded with each generation to support increasingly autonomous operations. The specific motor models were not detailed.

- **ROV2**: Equipped with a basic sensor set including a gyroscope, accelerometer, and magnetometer for orientation, complemented by a camera and 2 LEDs.
- **ROV3**: Added an inertial sensor, a pressure sensor for depth data, and a leakage detection device for safety.
- **ROV4**: Significantly upgraded with an integrated AHRS, sonar, and hydrophones, greatly expanding its autonomous capabilities. Lighting was also improved to wide-angle LEDs delivering 4500 Lumens.
- **Blue Nemo**: Built upon ROV4's sensor suite, adding another ultrasonic sonar and a Doppler Velocity Log (DVL) for more precise navigation.

2.2 Chosen Control Hardware

This topic was not discussed in this design solution. The paper focuses on the mechanical evolution and high-level capabilities rather than the specific electronic control boards used.

2.3 Chosen Interfacing Architecture

This topic was not discussed in this design solution. The paper does not detail the software architecture or the specific communication protocols used between internal components.

3 Control Systems and System Modeling

3.1 ROV Communication Method

This topic was not discussed in enough detail. While the paper states that later models could be remotely operated or function autonomously, it does not specify the communication method (e.g., tether specifications, data protocols, or wireless communication standards).

3.2 Control Architecture

The control philosophy evolved from direct remote operation towards full autonomy.

- **ROV2/ROV3**: Were primarily designed as Remotely Operated Vehicles, controlled directly by a human operator.
- **ROV4**: Was a transitional hybrid, featuring two control modes that allowed it to perform basic tasks autonomously or be remotely operated.
- **Blue Nemo**: Was designed from the ground up with full autonomy in mind, supported by its advanced sensor package including a DVL and multiple sonars. The specific control algorithms were not detailed.

3.3 System Modeling

System modeling was performed through buoyancy calculations and Computational Fluid Dynamics (CFD) to optimize energy efficiency and hydrodynamic performance.

- **Buoyancy**: Early models did not account for buoyancy in the design phase, leading to sub-optimal energy usage (ROV2 was negatively buoyant, ROV3 was too positively buoyant). Later designs like Blue Nemo calculated mass and volume at the design stage to achieve slightly positive buoyancy, a safety feature allowing the vehicle to surface in case of system failure.
- **Hydrodynamics (CFD)**: Flow analysis showed that the cylindrical hull and open-frame design of ROV4 had the best hydrodynamic performance with the least turbulence. The earlier prism-shaped hulls of ROV2 and ROV3 were less efficient. Blue Nemo retained the good characteristics of ROV4, although minor turbulence was introduced due to different thruster mounting points.

VITA1: An Unmanned Underwater Vehicle Prototype for Operation in Underwater Tunnels

Team: Vitor A. M. Jorge, Pedro Daniel de Cerqueira Gava, Juan R. B. F. Silva, et al. **Date:** August 14, 2025**Cite:** "[Jorge et al., 2021]"

Abstract

This paper presents VITA1, a compact Unmanned Underwater Vehicle (UUV) prototype specifically designed for safe and effective operation within the challenging environment of fully flooded, large-scale underwater tunnels, such as those found in hydroelectric power plants. These environments are often characterized by high water turbidity and a complete lack of GPS, making navigation difficult. VITA1's system architecture integrates a sophisticated suite of sonar-based sensors to provide robust situational awareness and enable both manual and future autonomous operations. The system's effectiveness was validated through experiments in a pool, a lake, and finally inside a hydropower plant tunnel.

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1 Design Choices and Architecture

1.1 Materials

This topic was not discussed in this design solution. The paper focuses on the system architecture and sensor integration rather than the specific materials used for the frame and enclosures.

1.2 Waterproofing and Chassis Design

The VITA1 prototype is designed to be mechanically robust and compact, with dimensions of 0.6m (W) x 0.6m (L) x 0.35m (H) and a weight of 25 kg. This compact design is suitable for maneuvering in confined spaces. The chassis provides a stable platform for a dense array of sensory equipment. The electronics hardware layout was based on the Bluerov2 Heavy configuration but was modified to include additional components like a USB hub and an Ethernet switch to support the extensive sensor suite. Waterproofing is implicit in the design of the UUV for underwater operation, but specific methods are not detailed.

1.3 Propeller Location and Prop Design Choice

The paper does not detail the thruster configuration or propeller design. However, it states a preference for a conventional, maneuverable design over a torpedo-like shape, which is less agile laterally. This implies a thruster layout optimized for maneuverability and stability, which is critical for operating safely within a tunnel. The vehicle uses the ArduSub firmware on a Pixhawk1, a platform commonly associated with vectored thruster configurations for 6-DOF control.

2 Hardware and Software

2.1 Chosen Propeller Motors and Other Sensors

The UUV integrates a comprehensive sensor suite designed to overcome the challenges of GPS-denied, low-visibility environments. The specific motor models are not mentioned.

- **Forward Looking Sonar (FLS)**: A Tritech Gemini-720im imaging sonar provides fast, 2D forward-looking spatial information, serving as the primary sensor for obstacle avoidance for the human pilot or an autonomous navigation system.
- **Profiling Sonar (PS)**: An Imagenex 881L mechanical scanning sonar is used to acquire detailed cross-sectional profiles of the tunnel, which is essential for mapping and structural analysis.

- **Fast Collision Detection (FCD)**: An array of four BlueRobotics Ping echosounders provides 360-degree, real-time distance measurements. They are pointed up, down, left, and right relative to the vehicle frame to offer immediate proximity warnings and complement the forward-looking and profiling sonars.
- **Vision**: A low-light camera with a tilt unit is included for close-range visual inspection when water clarity permits.
- **Navigation**: An entry-level Doppler Velocity Log (DVL) provides accurate velocity estimates, which are fused with data from the IMU within the Pixhawk1 to improve dead-reckoning accuracy.

2.2 Chosen Control Hardware

The onboard control system uses a combination of commercially available and widely supported open-source hardware.

- A **Pixhawk1** flight control unit running the ArduSub firmware handles the low-level flight control, state estimation (fusing IMU and DVL data), and motor commands. The choice to abdicate a standalone, high-cost INS was a key design decision.
- A **Raspberry Pi 3 B+** serves as the main onboard computer. It interfaces with the Pixhawk and the various sensor modules, running the Robot Operating System (ROS) to manage data integration and communication.

2.3 Chosen Interfacing Architecture

The software and hardware are integrated into a cohesive system using standard protocols and frameworks. The architecture is separated into four functional modules: Vision, Forward Looking Sonar (FLS), Profiling Sonar (PS), and Fast Collision Detection (FCD).

- **Communication**: The UUV is connected to a topside control station via a 300m tether cable, which provides an Ethernet link.
- **Onboard Network**: An Ethernet switch connects the high-bandwidth sonar sensors (FLS and PS) and the Raspberry Pi. A USB hub connects the grid of echosounders (FCD module) to the Raspberry Pi.
- **Software**: The system uses the Robot Operating System (ROS) as the primary integration framework. Communication between the Raspberry Pi and the Pixhawk is handled via the MAVLink protocol, using the MAVROS package in ROS. The topside computer runs QGroundControl for manual piloting and a UUV User Interface within the ROS network for sensor data visualization and logging.

3 Control Systems and System Modeling

3.1 ROV Communication Method

The VITA1 prototype operates as a tethered ROV. It uses a 300-meter umbilical cable that provides an Ethernet connection to the topside control station. This allows for reliable, high-bandwidth, real-time transfer of data from its extensive sensor suite (multiple sonars, camera) and telemetry from the Pixhawk, as well as sending control commands from the operator to the vehicle.

3.2 Control Architecture

The system is designed for both manual (ROV) operation and future autonomous (AUV) operation. In its current implementation, it is manually controlled by a pilot using the QGroundControl software on the topside computer. The control architecture relies on the ArduSub firmware running on the Pixhawk1, which handles the low-level vehicle stabilization and response to operator commands. The ROS network integrates all sensor data and provides it to the operator through custom Heads-Up Displays (HUDs), significantly enhancing situational awareness for piloting in the difficult tunnel environment.

3.3 System Modeling

This topic was not discussed in this design solution. The paper does not present a mathematical or physics-based model of the UUV's dynamics. However, it does model the data from the Fast Collision Detection (FCD) module to create a normalized 2D coordinate system for the pilot's HUD. The vehicle's position relative to the surrounding walls is calculated as $(\frac{d_r}{d_l+d_r} - 0.5, \frac{d_u}{d_u+d_d} - 0.5)$, which places the UUV in a display space from [-0.5, 0.5] to provide an intuitive sense of its position within the tunnel's cross-section.

Design and Development of an X4-ROV

Team: Zainah Md. Zain, Maziyah Mat Noh, Khairul Ashraff Ab Rahim, Nurfadzillah Harun **Date:** August 14, 2025**Cite:** "[Zain et al., 2016]"

Abstract

This paper describes the design and development of the X4-ROV, a micro observation-class ROV intended for visual observation of underwater structures and environments. The primary design goals were low cost, high mobility and portability, and the capability for live video streaming. The vehicle features a torpedo-shaped hull and is propelled by four thrusters in an "X4" configuration. Its development leveraged and modified the open-source OpenROV platform for its electronic and software systems to accelerate the prototyping process.

1 Design Choices and Architecture

1.1 Materials

To meet the low-cost design goal, the prototype was constructed from readily available and inexpensive materials. The main body or hull is made from a standard PVC pipe. The end of the hull is sealed with a watertight flange made from laser-cut acrylic. To mount the four external thrusters to the hull, custom brackets were designed and produced using 3D printing. This combination of materials allowed for rapid and affordable prototyping while providing a functional and water-resistant structure.

1.2 Waterproofing and Chassis Design

The X4-ROV is designed with a torpedo-shaped hull to provide a streamlined profile. The main chassis is the PVC pipe itself, which houses all the internal electronic components, including the controller boards, wiring, and battery. Waterproofing is achieved by sealing the main acrylic flange at the end of the PVC tube. The paper does not specify the exact sealing method (e.g., O-rings, sealant). The four thrusters are mounted externally on the 3D-printed brackets, so only the wiring for the thrusters needs to pass through the sealed hull.

1.3 Propeller Location and Prop Design Choice

The ROV is named for its distinctive "X4" thruster configuration, which is key to its high maneuverability. It uses four thrusters that are allocated on the sides of the fuselage at equal intervals. The thrusters are arranged both vertically and horizontally to enable control of the vehicle's position and attitude across all 6 degrees of freedom (surge, sway, heave, roll, pitch, and yaw) through differential thrust. This layout provides the agility required for observation and inspection tasks. The specific design of the propellers themselves is not discussed, but they are driven by brushless DC motors.

2 Hardware and Software

2.1 Chosen Propeller Motors and Other Sensors

- **Motors**: The propulsion system utilizes brushless DC motors, each controlled by a dedicated Electronic Speed Controller (ESC). The specific model of the motors is not mentioned. A test of a single thruster was performed in a tank, which measured a maximum thrust of 1.25 kg.
- **Sensors**: For navigation and orientation, the ROV is equipped with an Inertial Measurement Unit (IMU), a compass, and a depth sensor. For its primary mission of visual observation, it uses a high-definition (HD) webcam connected to the onboard computer via USB.

2.2 Chosen Control Hardware

The electronic control system was adapted from the open-source OpenROV project. This platform was chosen to reduce development time and cost. The onboard control system is a dual-board setup:

- A **BeagleBone Black** microcomputer serves as the high-level controller. It is responsible for running the webserver that hosts the control interface, processing commands from the operator, and managing the video stream from the webcam.
- A controller board based on the **ATMega2560** (Arduino) acts as the low-level controller. It interfaces directly with the vehicle's sensors (IMU, compass, etc.) and sends precise PWM signals to the ESCs to control the thrusters. The standard OpenROV controller board was modified to support the additional thruster required for the X4 configuration.

2.3 Chosen Interfacing Architecture

The system architecture follows a client-server model based on the OpenROV software stack.

- **Topside (Client)**: The operator uses a standard laptop and a web browser to access the ROV's "cockpit" or control interface.
- **Communication**: The laptop is connected to the ROV via an ultra-thin two-wire tether. Control commands are sent from the browser to the ROV as 'Socket.io' messages, and live HD video is streamed back to the browser.
- **Vehicle (Server)**: Onboard the ROV, the BeagleBone Black runs a webserver and an event listener. It receives the 'Socket.io' messages, processes the commands, and communicates the desired actions to the Arduino board. The Arduino then calculates the appropriate PWM signals for each of the four thruster ESCs to execute the maneuver.

3 Control Systems and System Modeling

3.1 ROV Communication Method

The X4-ROV is a tethered vehicle. It uses an ultra-thin two-wire umbilical cable to connect to the operator's laptop on the surface. This wired connection facilitates real-time, high-bandwidth communication, which is essential for sending control commands to the vehicle and receiving a live HD video stream from its webcam.

3.2 Control Architecture

The vehicle is remotely controlled by a human operator. The control system is based on the OpenROV software, which was modified to suit the X4-ROV's four-thruster hardware. The operator uses a web-browser-based cockpit running on a laptop to pilot the vehicle. Inputs from the operator are processed and sent over the tether to the BeagleBone Black, which then instructs the Arduino board to generate the correct PWM signals for the thrusters. The control is direct human-in-the-loop operation rather than autonomous.

3.3 System Modeling

A basic hydrodynamic analysis was performed to estimate the required thrust. The model accounted for the vehicle's mass (M_b) and the added mass (M_f) of the water displaced by its torpedo-shaped hull, using the formula $F = (M_b + M_f)a$. The added mass for the cylindrical body was calculated as $M_f = \rho\pi c R^2 L$. Based on the vehicle's dimensions (55mm radius, 430mm length) and a target acceleration of $0.5 m/s^2$, the required thrust was determined to be 3.743 N. Additionally, Computational Fluid Dynamics (CFD) simulations were run in SolidWorks to analyze the pressure distribution on the hull during forward motion and to visualize the water flow trajectory to study potential turbulence.

eROV: Preliminary Design of 5 DOF ROV using 6 Thrusters Configuration

Team: Eko Henfri Binugroho, Raden Sanggar Dewanto, Dadet Pramadihanto **Date:** August 14, 2025**Cite:** [Binugroho et al., 2018]

Abstract

This paper proposes the preliminary design of eROV, a Remotely Operated Vehicle (ROV) with 5 degrees of freedom (DOF) that utilizes a six-thruster configuration [Binugroho et al., 2018]. The vehicle is designed as a flexible and reliable platform for future underwater environment research up to 80m depth, with a specific focus on accommodating a large and diverse collection of scientific sensors. The design emphasizes maneuverability in the horizontal plane and includes passive roll stability [Binugroho et al., 2018].

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1 Design Choices and Architecture

1.1 Materials

The chassis of the eROV is constructed from 10mm thick aluminum plate from the 6000 series (AlMgSi), which was chosen for its high resistance to corrosion in seawater [Binugroho et al., 2018]. The dual hulls, which house the electronics and batteries, are made from AW class PVC pipe, rated to withstand the pressure at the target operational depth. Connections are made with stainless steel bolts [Binugroho et al., 2018].

1.2 Waterproofing and Chassis Design

The eROV is built on an open-frame aluminum chassis. Waterproofing is achieved by housing all electronic components within two large, pipe-shaped hulls made of PVC, located at the top of the vehicle [Binugroho et al., 2018]. This dual-hull design places the vehicle's center of buoyancy high, providing significant passive stability in the roll axis. The mechanical design was subjected to stress analysis to confirm that the PVC hulls could withstand the hydrostatic pressure at an 80m depth [Binugroho et al., 2018].

1.3 Propeller Location and Prop Design Choice

The ROV uses six thrusters to achieve 5-DOF motion (surge, sway, heave, yaw, and pitch), with roll being passively stabilized [Binugroho et al., 2018]. The thruster configuration is tailored for high maneuverability: four thrusters are located in the horizontal plane to provide strong and flexible control of surge, sway, and yaw. The remaining two thrusters are located vertically, but uniquely positioned at the front and rear of the vehicle (rather than the sides), which enables active control over the vehicle's pitch motion [Binugroho et al., 2018].

2 Hardware and Software

2.1 Chosen Propeller Motors and Other Sensors

The propulsion system consists of six T-200 underwater thrusters from BlueRobotics, which are lightweight and provide significant thrust [Binugroho et al., 2018]. The vehicle is designed to carry an extensive collection of high-end sensors for scientific research, including an ImpactSubsea ISM3D AHRS, a Tritech altimeter and side-scan sonar, two YSI EXO2 multi-parameter water quality sondes, a Kongsberg underwater vision camera, a Cubert spectral camera, and a Bar30 high-resolution pressure sensor for depth measurement [Binugroho et al., 2018].

2.2 Chosen Control Hardware

The control system is designed with a two-tiered architecture. A low-level controller based on an STM32F407 embedded system will be responsible for real-time tasks, including interfacing with the thrusters and primary navigation sensors (IMU and pressure sensor) [Binugroho et al., 2018]. A high-level controller, a Jetson TX2 board from NVIDIA, will be used for more computationally intensive tasks such as data processing from the cameras and sonar, data storage, and communication with the ground station [Binugroho et al., 2018].

2.3 Chosen Interfacing Architecture

The two controllers handle distinct functions. The low-level STM32 controller manages the basic motion control of the vehicle [Binugroho et al., 2018]. The high-level Jetson TX2 board acts as the main brain for mission management and data handling, interfacing with the more complex external sensors and managing communication with the surface [Binugroho et al., 2018]. This distributed architecture separates real-time control from high-level processing.

3 Control Systems and System Modeling

3.1 ROV Communication Method

The eROV is a tethered vehicle. The tether is used to supply high-voltage power from the surface ground station to the ROV. This power is used to simultaneously charge the onboard battery and power the systems, ensuring long-duration missions are possible [Binugroho et al., 2018]. The tether also serves as the communication link between the ROV and the remote operator [Binugroho et al., 2018].

3.2 Control Architecture

The power system is a key feature of the control architecture. The vehicle is equipped with an onboard 6-cell LiFePO4 battery pack and a Battery Management System (BMS) circuit [Binugroho et al., 2018]. The battery handles the high, instantaneous current demands of the thrusters during maneuvering, which prevents voltage drops that could occur with a long power-over-tether cable. The battery is continuously recharged from the high-voltage supply sent down the tether, creating a robust hybrid power system [Binugroho et al., 2018].

3.3 System Modeling

The paper presents a detailed kinematic and dynamic model for the eROV. The kinematic model is derived using the standard North-East-Down (NED) earth-fixed frame and a body-fixed frame, providing the transformation matrices for linear and angular velocities [Binugroho et al., 2018]. The nonlinear dynamic model is based on the standard marine vessel equation $M\dot{v} + C(v)v + D(v)v + g(\eta) = \tau$. This model is then simplified for control design purposes by assuming that roll motion is passively stabilized and that Coriolis effects are negligible due to the vehicle's symmetry. This results in simplified diagonal matrices for mass (M) and hydrodynamic damping ($D(v)$). The model also includes the restoring force vector $g(\eta)$ due to gravity and buoyancy, and a thruster configuration matrix that maps the individual thruster forces to the overall forces and moments on the vehicle [Binugroho et al., 2018].

Development of a Hybrid Underwater Vehicle for Visual Inspection of Bridge Piers

Team: Hayato Kondo, Shukichi Kobayashi, Takatsugu Tashiro, Noriaki Saigo, Toshifumi Hiraike, Kai Kuroki **Date:** August 14, 2025**Cite:** [Kondo et al., 2023]

Abstract

This paper introduces a novel hybrid underwater vehicle, capable of operating as both a Remotely Operated Vehicle (ROV) and an Autonomous Underwater Vehicle (AUV) [Kondo et al., 2023]. Its primary purpose is to perform photogrammetric surveys of large underwater structures, such as bridge piers, in challenging conditions like turbid water and strong currents. A key innovation is a unique linear lighting system designed to overcome the nonhomogeneous illumination and backscatter issues that typically hinder underwater photogrammetry when using spotlights, thereby enabling more reliable 3D model reconstruction [Kondo et al., 2023].

1 Design Choices and Architecture

1.1 Materials

The paper does not specify the exact materials used for the vehicle's body or frame. Key components mentioned include a clear acrylic window for the camera system and several pressure-resistant bottles for housing electronics and batteries [Kondo et al., 2023].

1.2 Waterproofing and Chassis Design

The vehicle has a unique, thin, streamlined shape in both its vertical and horizontal cross-sections, designed to minimize drag and allow it to operate close to surfaces in strong currents [Kondo et al., 2023]. The chassis fully encloses all thrusters to prevent entanglement with wires or ropes often found on underwater structures. A key design choice was to intentionally reduce the separation between the center of buoyancy and the center of gravity. This is achieved by arranging two large, heavy battery bottles vertically at the fore and aft of the vehicle, which decreases passive stability but significantly increases maneuverability in all 6 degrees of freedom (DOF) [Kondo et al., 2023].

1.3 Propeller Location and Prop Design Choice

The vehicle is equipped with twelve thrusters, all of which are mounted inside the body for protection [Kondo et al., 2023]. There are ten horizontal thrusters (four directing fore, four directing aft, and two directing lateral) and two vertical tunnel thrusters. The eight fore and aft thrusters utilize the Coanda effect, where their outflow is directed along the curved surface of the vehicle's body via wide nozzles. This configuration provides the same effect as vectored thrusters but within a thin, streamlined body, enabling full 6-DOF motion control [Kondo et al., 2023].

2 Hardware and Software

2.1 Chosen Propeller Motors and Other Sensors

The paper does not specify the type of motors used for the thrusters. The vehicle's sensor suite is comprehensive, including an Inertial Measurement Unit (IMU), a fluxgate magnet compass, and a pressure sensor for depth measurement [Kondo et al., 2023]. For navigation and positioning, it uses a bottom-facing Doppler Velocity Log (DVL), a side-facing DVL (for relative velocity to structures), a small-sized scanning sonar, and a transducer for acoustic communication and USBL positioning. The main payload is a photographic system consisting of a GigE camera and two linear lights designed for photogrammetry [Kondo et al., 2023].

2.2 Chosen Control Hardware

The control system is distributed across multiple processing units housed in pressure bottles. The main bottle contains a Main CPU for overall control and sensor processing, a GPU dedicated to processing image data from the GigE camera and IMU data, and an MPU for handling water leak detection and a 9-axis MEMS sensor [Kondo et al., 2023]. In addition, each of the two battery bottles contains its own MPU, which is responsible for managing the lithium-ion battery cells and sending control signals to the Electric Speed Controllers (ESCs) for the thrusters [Kondo et al., 2023].

2.3 Chosen Interfacing Architecture

The system utilizes a modern, networked architecture. Gigabit Ethernet is used for communication between the main CPU and the MPUs in the battery bottles, as well as for the DVLs [Kondo et al., 2023]. The GPU and IMU communicate via a high-speed serial link, while other sensors like the scanning sonar and acoustic modem use RS232C serial communication. A dedicated media converter is used to interface the topside optical fiber with the vehicle's internal Gigabit Ethernet network [Kondo et al., 2023].

3 Control Systems and System Modeling

3.1 ROV Communication Method

The vehicle is a hybrid AUV/ROV that supports two primary communication channels. For real-time teleoperation with live video, it uses a single-mode optical fiber core wire, which was chosen for its high bandwidth and minimal drag to reduce the risk of entanglement [Kondo et al., 2023]. As a backup and for autonomous operations, it is also equipped with an acoustic communication link. This acoustic system also provides USBL positioning data from the topside transducer array [Kondo et al., 2023].

3.2 Control Architecture

The control architecture is designed to be robust and flexible, supporting both ROV and AUV functionalities. In ROV mode, an operator can control the vehicle in real-time using the optical fiber link. If this link is severed, the main CPU detects the loss of communication and automatically transitions to AUV mode. In this mode, it continues its mission based on a pre-loaded plan and can receive limited commands from the operator via the acoustic communication channel before surfacing automatically [Kondo et al., 2023].

3.3 System Modeling

The paper does not present a mathematical dynamic model of the vehicle. Instead, it focuses on the modeling and principles of its novel photographic system for photogrammetry. It proposes using a system of linear lights mounted parallel to the vehicle's direction of motion. The principle is that as the vehicle moves and captures a sequence of images, any given point on the target surface (e.g., a point on a horizontal line) will be illuminated with the same intensity and from the same angle in every frame in which it appears. This constant illumination condition is critical for allowing Structure from Motion (SfM) algorithms to successfully find and match tie points between images, a major challenge in turbid underwater environments [Kondo et al., 2023].

Remotely Operated Vehicle (ROV) IRIS-SP for Underwater Inspection Tasks

Team: Alok Sahu, Debasish Ghose, P. S. Sastry **Date:** August 14, 2025**Cite:** [Sahu et al., 2017]

Abstract

This paper presents the complete design and operation of IRIS-SP, a prototype Remotely Operated Vehicle (ROV) designed for operations at depths of up to 30 meters [Sahu et al., 2017]. The vehicle is intended as a competitive, entry-level platform optimized for size, weight, and cost. It serves as a proof of concept for underwater search, surveillance, monitoring, and data collection tasks, with a majority of its subsystems, including thrusters and electronics, designed and manufactured in-house to address the challenges of the underwater environment [Sahu et al., 2017].

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1 Design Choices and Architecture

1.1 Materials

The main frame and electronics housing of IRIS-SP is a single, clear acrylic capsule-shaped container, which provides structural integrity and visibility of the internal components [Sahu et al., 2017]. This container is attached to a 3D-printed U-Clamp that serves as a mounting point for the thrusters. To achieve neutral buoyancy, mild steel is used as dead weight, as the acrylic housing provides more than enough buoyancy on its own [**?**].

1.2 Waterproofing and Chassis Design

The design integrates the frame, electronics housing, and buoyancy into a single unit to minimize size and complexity [Sahu et al., 2017]. The capsule container is constructed from two acrylic domes and a central acrylic tube, fastened together on each side. The primary waterproof seal is an innovative PVC tube-enclosed O-ring. In-house designed hull penetrators are used for cable pass-throughs. These penetrators are sealed using rubber bushings coated with silicone and resin to ensure they are watertight at the target depth [Sahu et al., 2017].

1.3 Propeller Location and Prop Design Choice

The ROV is equipped with four thrusters, providing control in three axes of motion (surge, heave, and yaw) [Sahu et al., 2017]. Two thrusters are mounted horizontally on the 3D-printed U-Clamp to provide forward/reverse translational motion (surge) and rotational motion (yaw). Two additional thrusters are mounted vertically to provide translational motion in the z-axis (heave) [Sahu et al., 2017]. The propellers are 48 mm boat propellers directly coupled to the motors [Sahu et al., 2017].

2 Hardware and Software

2.1 Chosen Propeller Motors and Other Sensors

The thrusters were designed in-house using RC-grade components to reduce weight and cost. They are built from Turnigy NTM 28-30S 800KV brushless out-runner motors, which are typically used for quadrotors [Sahu et al., 2017]. The motor windings are protected with a conformal coating and the wires are sealed with epoxy. The motors are controlled by Quick Series 30A Electronic Speed Controllers (ESCs) designed for RC cars, which allow for bidirectional control [Sahu et al., 2017]. The sensor suite includes a DS18B20 waterproof temperature sensor, a BMP180 for internal hull temperature and pressure, an MPU6050 IMU for an auto-level feature, and a water drop sensor for leak detection. An SJCAM M20 Action camera provides the video feed [Sahu et al., 2017].

2.2 Chosen Control Hardware

The control system is based on hobby-grade electronics to minimize cost. The topside Tether Control Unit (TCU) is built around an Arduino Mega 2560 microcontroller fitted with a custom-designed shield PCB [Sahu et al., 2017]. The onboard control system, housed within the acrylic capsule, uses an Arduino Nano microcontroller mounted on a custom-designed sensor board [Sahu et al., 2017].

2.3 Chosen Interfacing Architecture

The system architecture is split between the topside TCU and the bottomside ROV electronics. The TCU integrates a 7-inch monitor for video, an LCD for sensor data, and a PS2 controller for pilot input [Sahu et al., 2017]. The topside Arduino Mega communicates with the bottomside Arduino Nano via a UART serial protocol over the tether. The onboard electronics are divided into two custom PCBs: a power board and a sensor board. The power board manages the two 12V LiPo batteries, connects to the four ESCs, and houses power monitoring sensors. The sensor board houses the Arduino Nano, the IMU, and the pressure/temperature sensors, and acts as the central hub for onboard processing [Sahu et al., 2017].

3 Control Systems and System Modeling

3.1 ROV Communication Method

Communication between the surface and the ROV is achieved through a 30-meter tether. The tether consists of a two-core shielded cable for bidirectional UART data communication and a separate RG 174 coaxial cable for video transmission from the camera to the TCU monitor [Sahu et al., 2017].

3.2 Control Architecture

The control architecture is based on direct teleoperation. The pilot uses a PS2 joystick connected to the TCU. The topside code, running on the Arduino Mega 2560, interprets the joystick inputs and implements a proportional control algorithm to determine the required speed and direction for each of the four thrusters [Sahu et al., 2017]. These commands are then sent as a data packet to the bottomside Arduino Nano, which executes the commands by sending PWM signals to the ESCs. The bottomside code also continuously collects sensor data and transmits it back to the TCU for real-time monitoring, data logging to an SD card, and alarm generation [Sahu et al., 2017].

3.3 System Modeling

This paper focuses on the mechatronic design and experimental validation of the ROV prototype rather than on theoretical system modeling. No mathematical model of the vehicle's dynamics is presented. The control system is a direct proportional controller based on the operator's joystick inputs. The software does include an "Auto Level" feature which uses data from the MPU6050 IMU, but the specific algorithm for this feature is not detailed [Sahu et al., 2017].

Kalypso: An inspection AUV for aquaculture

Team: Nikolaos Manos, Ergina Kavallieratou, Nikos Vasilopoulos **Date:** August 14, 2025**Cite:** [Manos et al., 2024]

Abstract

Kalypso is a 3D-printed underwater robotic vehicle designed specifically for aquaculture management in the Mediterranean Sea [Manos et al., 2024]. It is a hybrid system that can function autonomously (AUV) for routine inspection of fish farm nets—detecting structural damage, dead fish, and biofouling—and as a teleoperated ROV for direct intervention tasks such as net repair and debris removal. The goal is to provide a cost-effective, flexible, and sustainable solution to enhance inspection frequency, improve fish welfare, and reduce the costs and risks associated with manual diver operations [Manos et al., 2024].

1 Design Choices and Architecture

1.1 Materials

The main body of Kalypso is fabricated using 3D-printing technology with PLA plastic, allowing for precise customization and intricate detailing [Manos et al., 2024]. The watertight enclosure that houses the electronics is an acrylic tube with a 152 mm inner diameter. The end caps for this tube utilize aluminum plugs with O-rings for sealing the cable penetrations [Manos et al., 2024].

1.2 Waterproofing and Chassis Design

The chassis consists of a main 3D-printed body with two large, 3D-printed side parts that increase the vehicle's surface area for enhanced stability and also house the thrusters [Manos et al., 2024]. Waterproofing for the sensitive electronics is achieved via a central acrylic tube. This tube is sealed with two flanges, each fitted with three O-rings, and end caps. Cable penetrations are sealed using specially modified aluminum plugs with O-ring fittings. Additional weights and plastic corks acting as fixed ballast tanks are incorporated into the design to optimize balance and buoyancy [Manos et al., 2024].

1.3 Propeller Location and Prop Design Choice

Kalypso's maneuverability is enabled by an eight-thruster configuration that provides the vehicle with six degrees of freedom (6-DOF) [Manos et al., 2024]. The paper states the thrusters are "strategically positioned" to grant precise navigation and versatility, allowing for comprehensive inspection of fish farm nets. While the exact layout is not detailed in the text, images suggest a vectored configuration with four horizontal and four vertical/lateral thrusters, similar to that of the BlueROV2 [Manos et al., 2024].

2 Hardware and Software

2.1 Chosen Propeller Motors and Other Sensors

The paper does not specify the model of the eight thruster motors. The sensor suite includes leak sensors, underwater ultrasonic distance sensors, a pressure sensor, an Inertial Measurement Unit (IMU), and twin front and rear USB cameras [Manos et al., 2024]. For visibility in low-light conditions, the vehicle is equipped with 12V silicone-impregnated LED lighting [Manos et al., 2024]. The entire system is powered by two 14.8V, 10,000 mAh LiPo batteries [Manos et al., 2024].

2.2 Chosen Control Hardware

The control system employs a distributed, three-platform architecture to handle its diverse computational needs [Manos et al., 2024]. A Pixhawk 4 board is responsible for the low-level navigation and control of the vehicle. A Raspberry Pi 3 serves as the central processing unit for general onboard computation and data processing tasks. For computationally intensive tasks, a high-performance mini PC with an Intel Core i7 processor and an Nvidia GeForce GTX 1660 Ti graphics card is used, dedicated to running advanced computer vision and image processing algorithms [Manos et al., 2024].

2.3 Chosen Interfacing Architecture

The three main hardware platforms work in concert. The Pixhawk handles the real-time flight control and stabilization based on sensor inputs [Manos et al., 2024]. The Raspberry Pi acts as a mid-level controller, likely managing communication and mission logic. The powerful mini PC is the high-level processor, receiving video streams and running the complex algorithms for navigation and hole detection. The specific communication protocols and data exchange methods between these three components are not detailed in the paper [Manos et al., 2024].

3 Control Systems and System Modeling

3.1 ROV Communication Method

Kalypso is a hybrid vehicle capable of operating in two distinct modes. As an ROV, it is operated as a tethered, manual vehicle, allowing a human operator to perform complex interventions [Manos et al., 2024]. As an AUV, it operates as a tetherless, autonomous vehicle, executing pre-planned missions inside the net cages to record video for later analysis [Manos et al., 2024].

3.2 Control Architecture

The control architecture differs between modes. In manual ROV mode, the operator can use semi-automatic flight modes such as "stabilize mode" (maintains heading) and "depth hold mode" (maintains heading and depth) [Manos et al., 2024]. In autonomous AUV mode, the vehicle relies on a navigation procedure that uses data from the IMU and ultrasonic distance sensors to move parallel to the fish net. This procedure is described by a flowchart and includes logic for maintaining distance, turning at corners, and performing corrective moves to handle sensor inaccuracies. A separate, vision-based procedure was developed to autonomously detect holes in the nets from the captured video feed [Manos et al., 2024].

3.3 System Modeling

The paper does not present a mathematical model of the vehicle's dynamics. The navigation and control strategies are based on a heuristic, rule-based approach rather than a model-based controller. The navigation logic is explicitly defined in a flowchart, which dictates the vehicle's actions based on sensor inputs (e.g., "if distance > 1.3m, corrective move towards net") [Manos et al., 2024]. Similarly, the vision system for hole detection is described as a multi-step image processing algorithm (frame resizing, grayscaling, binarization, filtering) rather than a model-based detection system [Manos et al., 2024].

Design and Control of a Convertible ROV

Team: Hyeungsik Choi, Hanil Park, Sangki Chung, and Jeongmin Seo **Date:** August 14, 2025**Cite:** [Choi et al., 2012]

Abstract

This paper presents the KCROV, a convertible, six-degree-of-freedom (6-DOF) underwater robot designed to function as either a Remotely Operated Vehicle (ROV) or an Autonomous Underwater Vehicle (AUV) [Choi et al., 2012]. The primary purpose is to overcome the single-task limitation of traditional underwater vehicles by creating a versatile platform. In ROV mode, it is equipped with a manipulator and operated via a tether for interventional tasks. In AUV mode, the manipulator and tether are removed, converting it into a streamlined vehicle for autonomous exploration missions [Choi et al., 2012].

1 Design Choices and Architecture

1.1 Materials

The frame of the KCROV is constructed from aluminum plate [Choi et al., 2012]. The main housings for control systems, power, and batteries are cylindrical to withstand pressure [Choi et al., 2012].

1.2 Waterproofing and Chassis Design

The KCROV features a streamlined hull to minimize the effects of ocean currents [Choi et al., 2012]. The chassis is an open-frame design consisting of an upper body frame, a middle support frame for thrusters, a bottom frame supporting the pressure housings, and an exterior support frame [Choi et al., 2012]. Waterproofing for the electronics and power systems is achieved through cylindrical pressure housings composed of a main body, a head cap, and an end cap. For the custom-built manipulator, a dual oil sealing method was developed to ensure it is waterproof [Choi et al., 2012].

1.3 Propeller Location and Prop Design Choice

The vehicle is equipped with a total of seven thrusters to achieve 6-DOF motion control [Choi et al., 2012]. Four horizontal thrusters are symmetrically located at the corners of the hull to actuate surge, sway, and yaw movements. Three vertical thrusters are deployed to control heave, pitch, and roll rotation [Choi et al., 2012]. The thrusters utilize a direct driving mechanism with a gearless BLDC motor, which simplifies the waterproof structure and provides direct power transmission without the need for a speed reducer or magnetic coupling [Choi et al., 2012].

2 Hardware and Software

2.1 Chosen Propeller Motors and Other Sensors

The propulsion system uses seven 300W Brushless DC (BLDC) motors [Choi et al., 2012]. The sensor suite for navigation includes a Doppler Velocity Logger (DVL), an Inertial Measurement Unit (IMU), an Ultra-Short Baseline (USBL) positioning system, and a depth sensor [Choi et al., 2012]. For operation in AUV mode, a GPS and a wireless communication system are added for use when the vehicle is on the surface [Choi et al., 2012]. The ROV is also equipped with a custom-developed electric underwater manipulator with six joints [Choi et al., 2012].

2.2 Chosen Control Hardware

The control system for both ROV and AUV modes is based on a common set of processors. The main microprocessor is a Texas Instruments TMS320c28335, which is connected to an ATxmega128A1 processor that handles data processing from the various sensors [Choi et al., 2012]. A dedicated sensor fusion data processing board was developed incorporating these microprocessors to manage navigation data [Choi et al., 2012].

2.3 Chosen Interfacing Architecture

The ATxmega128A1 processor is connected to the distributed sensors via a simple RS-435 communications link [Choi et al., 2012]. This processor then transmits the processed sensor data to the main TMS320c28335 microprocessor through a Serial Communication Interface (SCI) bus. In ROV mode, operator commands are received via an optical fiber bus within the tether. The control board communicates with the thrusters using RS485 communication [Choi et al., 2012].

3 Control Systems and System Modeling

3.1 ROV Communication Method

In ROV mode, the vehicle is controlled through a long tether cable which contains an optical fiber bus for high-speed command signals from the operator's console [Choi et al., 2012]. The control board communicates internally with the thrusters via an RS485 link. In AUV mode, the tether is removed, and the vehicle relies on a wireless RF communication system to transmit data when it surfaces [Choi et al., 2012].

3.2 Control Architecture

The KCROV has distinct control architectures for its two operational modes. In ROV mode, it is teleoperated, with vehicle motion directly controlled by operator commands, and it receives 280V DC power from the surface ship via the tether [Choi et al., 2012]. In AUV mode, it operates on an autonomous control algorithm for navigation and is powered by an onboard battery assembly consisting of lithium-ion cells [Choi et al., 2012]. The core processing hardware remains the same, but the control software and power systems are switched depending on the configuration.

3.3 System Modeling

The navigation and control system employs an Extended Kalman Filter (EKF) algorithm for state estimation [Choi et al., 2012]. The EKF is embedded in the TMS320c28335 microprocessor and is used to fuse data from the DVL, IMU, USBL, and depth sensors to produce an accurate estimate of the vehicle's state and correct for accumulated navigation errors [Choi et al., 2012]. The paper also presents a hydrodynamic analysis to predict the AUV's performance, using the drag equation $v = \sqrt{\frac{F \times g}{0.5 \times \rho \times C_d \times A}}$ to estimate a maximum speed of approximately 3 knots [Choi et al., 2012].

Design and Modeling of a Low-Cost Observation Class ROV for Dam Inspection

Team: Abdelmalek Laidani, Mohammed Boudria, et al. **Date:** August 14, 2025**Cite:** [Laidani et al., 2022]

Abstract

This paper describes the design and modeling of a low-cost, small, and high-performance observation-class Remotely Operated Vehicle (ROV) [Laidani et al., 2022]. The vehicle is designed to be a hybrid, with both teleoperated (ROV) and autonomous (AUV) capabilities. Its primary mission is the inspection of dams, including checking the structural integrity of the walls and measuring siltation levels, thereby offering a safe and cost-effective alternative to using human divers or emptying the dam [Laidani et al., 2022].

1 Design Choices and Architecture

1.1 Materials

The ROV's frame is constructed from polymer materials, primarily PLA (Poly Lactic Acid) for 3D printed components and PVC (Poly Vinyl Chloride) for the central tube [Laidani et al., 2022]. These materials were chosen because they are readily available, easy to work with, lightweight, and sufficiently robust for the application. The main hull is a PN6 pressure PVC tube with a 125mm external diameter [Laidani et al., 2022].

1.2 Waterproofing and Chassis Design

The vehicle features a closed, torpedo-shaped hull, which offers good hydrodynamic characteristics and is simple to manufacture [Laidani et al., 2022]. The main shell consists of three parts: a front flange, the central PVC tube, and a rear flange. These parts are assembled using threaded rods and nuts. Waterproofing is achieved using a static sealing system with two NBR (Nitrile Butadiene Rubber) O-rings on each flange and sealed cable glands for all cable penetrations [Laidani et al., 2022].

1.3 Propeller Location and Prop Design Choice

The propulsion system consists of four thrusters, enabling 4-DOF motion (Surge, Heave, Roll, and Yaw) [Laidani et al., 2022]. The thruster design is inspired by the BlueRobotics T100/T200, featuring 3-blade boat-style propellers which are efficient for the application. The thrusters are mounted to the main frame via supports that attach to the same threaded rods used for the hull assembly, allowing for adjustable positioning [Laidani et al., 2022]. The final configuration places two thrusters horizontally for surge/yaw and two vertically for heave/roll [Laidani et al., 2022].

2 Hardware and Software

2.1 Chosen Propeller Motors and Other Sensors

The propulsion system uses A2212/13T Brushless DC (BLDC) motors, with the windings sealed in a protective resin, making them suitable for underwater use without additional sealing [Laidani et al., 2022]. They are controlled by reversible 30A Electronic Speed Controllers (ESCs). The sensor package includes an MS5540C piezoelectric pressure sensor for depth measurement and an IMU composed of an MPU6050 (accelerometer and gyroscope) and an LSM303DLHC (magnetometer) for attitude sensing. An observation camera using an OV5647 5-megapixel sensor provides the video feed [Laidani et al., 2022].

2.2 Chosen Control Hardware

The control system follows a master-slave architecture. The "brain" of the ROV is a Raspberry Pi (model 3b+), which acts as the master controller [Laidani et al., 2022]. Arduino Uno and Nano boards are used as slave microcontrollers. They function as acquisition cards, gathering data from the sensors and executing low-level commands to drive the thrusters, as instructed by the Raspberry Pi [Laidani et al., 2022].

2.3 Chosen Interfacing Architecture

The Raspberry Pi, having a network card, allows the ROV to be treated as a connected object controllable from a ground station via a tether [Laidani et al., 2022]. Internally, the Arduino boards communicate with the IMU sensors using the I2C protocol. The camera interfaces with the Raspberry Pi using the MiPi-CSI protocol. The Arduinos communicate with the Raspberry Pi to relay sensor data and receive motor commands, creating a hierarchical and organized data flow [Laidani et al., 2022].

3 Control Systems and System Modeling

3.1 ROV Communication Method

The ROV is connected to a ground station computer via a tether, which facilitates remote control [Laidani et al., 2022]. The vehicle is designed to be a hybrid, allowing for both direct teleoperation and future implementation of autonomous functionalities [Laidani et al., 2022].

3.2 Control Architecture

The ROV is powered by an onboard battery system, a choice made to avoid the extra weight, volume, and drag associated with a power-over-tether system [Laidani et al., 2022]. A power balance was calculated to select a suitable battery for the energy demands of the thrusters and electronics. The control architecture is centralized on the Raspberry Pi, which processes commands from the surface and manages the slave Arduino boards responsible for real-time sensor reading and actuator control [Laidani et al., 2022].

3.3 System Modeling

A comprehensive 6-DOF mathematical model of the ROV is presented based on the Fossen formalism [Laidani et al., 2022]. The model was developed using a combination of theoretical and computational methods. The rigid-body mass (M_{RB}) and Coriolis (C_{RB}) matrices were determined from the 3D CAD model. Hydrodynamic drag coefficients for the damping matrix ($D(\nu)$) were calculated using Computational Fluid Dynamics (CFD) analysis in SolidWorks, with the results fitted to curves in MATLAB. The added mass matrix (M_A) was derived theoretically using strip theory, and the restoring forces vector ($g(\eta)$) was calculated from the vehicle's weight and buoyancy distribution. The thrust force of the custom-built thrusters was characterized experimentally using a test bench. This complete model was implemented in MATLAB/Simulink to simulate and validate the vehicle's dynamic behavior [Laidani et al., 2022].

System identification of a prototype small scale ROV for depth control

Team: Mohd Shahrieel Mohd Aras, et al. **Date:** August 14, 2025**Cite:** [Aras et al., 2015]

Abstract

This paper presents the design of a small-scale Remotely Operated Vehicle (ROV), UTERG-ROV 2, and the modeling of its depth control response [Aras et al., 2015]. The primary objective was to develop a low-cost ROV for research purposes that improves upon a previous model (UTERG-ROV 1) by minimizing hydrodynamic forces and increasing energy efficiency. A key focus of the work was to use the System Identification technique to derive a mathematical model of the vehicle's dynamics from experimental data, which could then be used to design an effective automatic depth controller [Aras et al., 2015].

1 Design Choices and Architecture

1.1 Materials

The body of the UTERG-ROV 2 is constructed from Perspex (acrylic) and then covered with fiberglass to provide a stronger bond and a waterproof surface [Aras et al., 2015]. Cement is used as a finishing material to create a smooth outer surface, presumably to improve hydrodynamic performance [Aras et al., 2015].

1.2 Waterproofing and Chassis Design

The ROV features a fully enclosed, faired body design, a significant departure from the open-frame design of its predecessor. This was done to minimize hydrodynamic forces [Aras et al., 2015]. The fiberglass-covered acrylic body serves as the main waterproof chassis, housing all the internal components. For depth control, the vehicle is equipped with a flexible ballast tank system, which consists of a medical blood bag and an electric motor pump to take in or expel water, thus changing the vehicle's buoyancy [Aras et al., 2015].

1.3 Propeller Location and Prop Design Choice

The paper's text does not specify the thruster layout of the new ROV, as its primary focus is on depth control modeling. However, the CAD drawings provided (Fig. 2) show a configuration of four thrusters, with two mounted horizontally at the rear for forward motion and steering, and two mounted vertically for heave (depth) control. The propellers are 2-blade models with a 45-degree pitch angle [Aras et al., 2015].

2 Hardware and Software

2.1 Chosen Propeller Motors and Other Sensors

The thrusters are custom-made using 12V DC motors coupled to 2-blade propellers [Aras et al., 2015]. The main sensors used for the depth control experiments are a pressure sensor (MPX4250GP) to measure depth and an Inertial Measurement Unit (IMU) sensor to provide attitude information such as pitch and roll. The ROV is also equipped with an underwater inspection camera with 3 IR LEDs for low-light operation and an underwater LED torch for illumination [Aras et al., 2015].

2.2 Chosen Control Hardware

Data acquisition from the sensors is performed using a National Instruments (NI) data acquisition card (NI-card) [Aras et al., 2015]. The paper mentions that all sensors are controlled by a circuit placed inside an integrated sensor box, but the specific microcontroller or processing unit used for the vehicle's control is not identified [Aras et al., 2015].

2.3 Chosen Interfacing Architecture

The interfacing architecture is centered around the NI-card. Data signals from the onboard pressure sensor and IMU are transmitted to the NI-card, which digitizes the data and transfers it to a laptop for monitoring and recording [Aras et al., 2015]. This setup is used specifically for collecting the experimental data needed for the system identification process.

3 Control Systems and System Modeling

3.1 ROV Communication Method

While not explicitly detailed, the use of an NI-card for data transfer implies a standard tethered connection between the ROV and the surface laptop, carrying sensor data and control signals.

3.2 Control Architecture

The control architecture focuses on achieving stable depth control. Based on the mathematical model obtained through system identification, a conventional Proportional-Integral-Derivative (PID) controller was designed and simulated in MATLAB [Aras et al., 2015]. The simulation results showed that the PID controller could successfully regulate the ROV's depth, with the system output closely tracking the desired step input [Aras et al., 2015]. The controller parameters used were P=0.9, I=245, and D=0 [Aras et al., 2015].

3.3 System Modeling

The core contribution of this paper is its use of the System Identification technique to model the ROV's dynamics, rather than deriving a model from first principles [Aras et al., 2015]. An open-loop experiment was conducted in a lab tank, where a step input was applied to the vertical thrusters and the resulting change in depth (measured by the pressure sensor) was recorded over time. This input-output data was then imported into the MATLAB System Identification Toolbox. The toolbox was used to analyze the data and generate a second-order transfer function that accurately represents the depth response of the ROV. The paper provides the final transfer function and its equivalent state-space model, which was validated as being both controllable and observable [Aras et al., 2015].

Development of the MarmaROV Remotely Operated Underwater Vehicle System

Team: Cenk Ulu, Onur Canbak, M. Ufuk Altunkaya, Hüseyin Taşkın, Said Yayla **Date:** August 14, 2025**Cite:** [Ulu et al., 2017]

Abstract

The purpose of the MarmaROV system is to serve as a research and oceanographic tool for the scientific research vessel R/V TUBITAK Marmara [Ulu et al., 2017]. It is designed as a light-work class, open-frame ROV capable of operating at depths up to 1000m [Ulu et al., 2017]. The system is intended for tasks such as underwater observation, sampling, and handling objects up to 20kg with its robotic arm [Ulu et al., 2017].

1 Design Choices and Architecture

1.1 Materials

The main frame is constructed from **polypropylene**, supported by **aluminum beams**, materials chosen to provide robustness and support modularity [Ulu et al., 2017]. The pressure vessels for electronics are manufactured from **aluminum** to withstand 100 bars of pressure [Ulu et al., 2017]. **Syntactic buoyancy foam** is used to ensure the vehicle is positively buoyant [Ulu et al., 2017].

1.2 Waterproofing and Chassis Design

MarmaROV uses a "wet design" or "open frame" concept, where components are mounted on a frame rather than inside a single watertight hull [Ulu et al., 2017]. This approach was chosen for its high maneuverability, robustness, and ease of maintenance [Ulu et al., 2017]. Waterproofing for sensitive electronics is achieved by housing them in three separate, custom-designed **aluminum pressure vessels** for communication, power, and thruster drivers [Ulu et al., 2017].

1.3 Propeller Location and Prop Design Choice

The ROV features a thruster configuration providing five degrees of freedom (surge, sway, yaw, heave, and roll) [Ulu et al., 2017]. The layout consists of four horizontal thrusters in a vectored arrangement and two vertical thrusters [Ulu et al., 2017]. This configuration was chosen to enhance maneuverability. The specific thruster models were selected based on the results of CFD analyses to ensure they could provide the required thrust for a nominal speed of 3 knots [Ulu et al., 2017].

2 Hardware and Software

2.1 Chosen Propeller Motors and Other Sensors

The specific motor model is not named, but the thrusters were selected from commercial options based on performance requirements [Ulu et al., 2017]. The vehicle is equipped with a comprehensive sensor suite for navigation and inspection: Ultra Short Base Line (USBL) positioning system, Attitude and Heading Reference System (AHRS), Doppler Velocity Log (DVL), depth sensor, acoustic altimeters, GPS, a low-light navigation camera, an HD inspection camera on a pan-tilt unit, and a forward-looking imaging sonar [Ulu et al., 2017].

2.2 Chosen Control Hardware

The system is operated from a dedicated control room on the research vessel, containing two computers (control and video recording), six monitors, and a portable control unit with joysticks and buttons [Ulu et al., 2017]. The control software is developed in a softPLC-based environment [Ulu et al., 2017]. The specific models of the onboard microcontrollers within the pressure vessels are not detailed [Ulu et al., 2017].

2.3 Chosen Interfacing Architecture

The system architecture is designed for deep-sea operations. A 20 kVA power unit on the ship sends high-voltage power down an armored umbilical cable to a Tether Management System (TMS) [Ulu et al., 2017]. The TMS manages the final 1000m tether to the ROV, which carries both power and a single-mode fiber optic line for all data communication (video, sensors, control) [Ulu et al., 2017]. The ROV also features a five-function robotic arm for sample collection and manipulation [Ulu et al., 2017].

3 Control Systems and System Modeling

3.1 ROV Communication Method

The primary communication link is a **fiber optic line** inside the electro-optical umbilical and tether [Ulu et al., 2017]. This high-bandwidth connection supports all video, sensor data, and command signals, which are managed using protocols like RS485, Modbus RTU, and Ethernet [Ulu et al., 2017]. For underwater positioning, a USBL system uses acoustic communication between the ship and the ROV [Ulu et al., 2017].

3.2 Control Architecture

The ROV supports both manual and autonomous control modes. In manual mode, an operator uses joysticks to control the vehicle's movement [Ulu et al., 2017]. The autonomous capabilities include auto-depth, auto-yaw, auto-altitude, and roll stabilization, all of which are implemented using **PID control algorithms** [Ulu et al., 2017]. The system is managed through a custom graphical user interface with dedicated screens for operations and video overlay [Ulu et al., 2017].

3.3 System Modeling

While a full system model is not provided, the design process was informed by modeling. **Computational Fluid Dynamics (CFD) analyses** were performed to determine the hydrodynamic forces on the vehicle and to select appropriate thrusters capable of achieving the target nominal speed of 3 knots [Ulu et al., 2017]. The control system is described with a functional block diagram illustrating the feedback loop architecture [Ulu et al., 2017].

ArduinoSub-A Low-Cost ROV Kit for Ocean Engineering Education

Team: William Wang, Shuo Pang, Tongshu Wu, Bing Han **Date:** August 14, 2025**Cite: NOTE: Paper not found in provided .bib file. Authors: Wang, et al.**

Abstract

The ArduinoSub is a low-cost (under $1000) educational ROV kit designed for middle school to college students. Its purpose is to improve marine technical education by providing a hands-on platform for learning mechanics, electronics, programming, and ocean engineering principles. It is an observation-class ROV capable of waypoint navigation, path following, depth holding, and video recording.

1 Design Choices and Architecture

1.1 Materials

The main pressure housing is made from commercially available **Polyethylene (PE) pipes** to keep costs low. The front end of the housing is a transparent **acrylic dome** for the camera, and the back end is an **aluminum end cap** for cable penetrators. The thruster motor bearings are made of **304 stainless steel** for low noise and long life.

1.2 Waterproofing and Chassis Design

The chassis is built around a central PE pipe (125mm O.D.) that serves as the main waterproof pressure housing for the electronics. Two additional tubes on the bottom of the vehicle house the batteries, creating a low center of gravity for stability. The vehicle has a positive buoyancy of about 200 grams. Waterproofing is achieved through the sealed main housing, which uses an aluminum end cap with penetrators for the tether, sensors, and charging ports.

1.3 Propeller Location and Prop Design Choice

The ROV uses four thrusters in total: two forward thrusters for surge and yaw movements, and two vertical thrusters for heave and pitch movements. This configuration provides 4-DOF motion. The thrusters utilize a 2-blade propeller housed within a protective shroud.

2 Hardware and Software

2.1 Chosen Propeller Motors and Other Sensors

The thrusters are a custom-developed, low-cost integrated unit with a built-in Electronic Speed Controller (ESC) to save space inside the main housing. Each thruster can provide over 40N of thrust. The sensor suite includes an **MPU-9250 9-axis motion sensor** (for attitude), an **MS5837-30BA depth sensor**, and a leak detector. Vision is provided by an **analog HD CCTV camera** (1080p) on a tilt servo, supported by two 1500-lumen underwater lights.

2.2 Chosen Control Hardware

The main onboard controller is an **Arduino Mega 2560**, chosen for its popularity and ease of use in an educational context. The surface gamepad controller is built around an **Arduino Uno**. Power is provided by eight 21700 lithium-ion batteries (4S2P configuration), which allows for up to 2 hours of operation. A dedicated power management board handles battery charging and discharging.

2.3 Chosen Interfacing Architecture

The system is divided into the ROV and a surface unit, connected by a neutrally buoyant tether carrying four unshielded twisted pairs. The ROV's internal control unit consists of the controller board (Arduino Mega, sensors) and a power management board. The surface unit includes a gamepad with a small LCD for status display and a separate 5-inch LCD screen with a DVR for viewing and recording the analog video feed.

3 Control Systems and System Modeling

3.1 ROV Communication Method

Communication between the surface unit's Arduino Uno and the ROV's Arduino Mega 2560 occurs over the physical tether. The video is transmitted as an analog signal over the same tether. The choice of an analog HD camera was specifically made to ensure ultra-low latency for piloting.

3.2 Control Architecture

The software is an open-source, PID-based control solution written for the Arduino platform. It supports direct manual control via the surface gamepad as well as autonomous functions. The "intelligent motion control" software implements depth-hold and heading-hold algorithms using PID control. The entire software stack is open-source to encourage students to modify and upload their own code using the Arduino IDE.

3.3 System Modeling

This topic was not discussed in this design solution. The paper focuses on the hardware components, system architecture, and educational application of the kit rather than mathematical modeling.

PolROV (Polman Education Platform of Underwater Robot) Monitoring Navigation Design Using PID Controller Method

Team: Hilda Khoirunnisa, Sarosa Castrena Abadi, Pipit Anggraeni, Rudi **Date:** August 14, 2025**Cite:** [Khoirunnisa et al., 2024]

Abstract

PolROV is an educational platform designed to improve the navigation accuracy of underwater robots [Khoirunnisa et al., 2024]. Its primary purpose is to create an ROV that can reliably execute commands and maintain a stable position, with a specific focus on depth control using a PID controller [Khoirunnisa et al., 2024]. The system integrates with a LabVIEW interface for real-time monitoring and parameter tuning [Khoirunnisa et al., 2024].

1 Design Choices and Architecture

1.1 Materials

The flange endcap, a critical component for waterproofing, is custom-made from multiple layers of **acrylic material** [Khoirunnisa et al., 2024]. While not explicitly stated, the images suggest the main electronics enclosure is a transparent acrylic tube, and the external frame is made of plastic or 3D-printed components. Buoyancy foam is also used [Khoirunnisa et al., 2024].

1.2 Waterproofing and Chassis Design

The design features a central transparent tube to house the electronics, mounted on an external frame [Khoirunnisa et al., 2024]. A significant design effort focused on creating a custom, multi-layered acrylic flange endcap to ensure the electronics enclosure remains waterproof, which is a key mechanical component of the design [Khoirunnisa et al., 2024].

1.3 Propeller Location and Prop Design Choice

The ROV uses Brushless DC (BLDC) motors as thrusters [Khoirunnisa et al., 2024]. The hardware design images show a configuration with at least four horizontal thrusters (two on each side for surge/sway/yaw) and two vertical thrusters (one on each side for heave/pitch/roll) [Khoirunnisa et al., 2024]. The paper discusses the calculation of the optimal horizontal thruster tilt angle to align with the vehicle's center of gravity [Khoirunnisa et al., 2024].

2 Hardware and Software

2.1 Chosen Propeller Motors and Other Sensors

The vehicle is propelled by **Brushless DC (BLDC) motors** controlled by Electronic Speed Controllers (ESCs) [Khoirunnisa et al., 2024]. For vertical navigation and depth control, the ROV is equipped with two types of sensors: a **TF Luna Lidar sensor** and an **H710B pressure sensor**. The data from these sensors provides the feedback necessary for the PID depth controller [Khoirunnisa et al., 2024].

2.2 Chosen Control Hardware

The core controller is a **Raspberry Pi 4**, which runs the PID control logic and handles communication [Khoirunnisa et al., 2024]. The programming language used on the Raspberry Pi is Python [Khoirunnisa et al., 2024]. The motors are driven by ESCs connected to the Raspberry Pi's GPIO pins [Khoirunnisa et al., 2024].

2.3 Chosen Interfacing Architecture

The user interface is a graphical dashboard created in **NI LabVIEW**, which runs on a laptop [Khoirunnisa et al., 2024]. Communication between the ROV's Raspberry Pi and the LabVIEW interface is handled by the **MQTT protocol** over a wired TCP/IP connection [Khoirunnisa et al., 2024]. This architecture allows the user to input setpoints (e.g., desired depth) in LabVIEW, which are then published to the Raspberry Pi. The ROV processes the commands, and sensor data is published back to LabVIEW for real-time monitoring and graphing [Khoirunnisa et al., 2024].

3 Control Systems and System Modeling

3.1 ROV Communication Method

Communication between the ROV's Raspberry Pi and the user's laptop is conducted over a **wired TCP/IP connection** using the **MQTT (Message Queuing Telemetry Transport) protocol** [Khoirunnisa et al., 2024]. The Raspberry Pi acts as both an MQTT client and the broker for the network, while LabVIEW functions as another client. This method was chosen for its data transmission stability [Khoirunnisa et al., 2024].

3.2 Control Architecture

The control architecture is centered around a **PID (Proportional-Integral-Derivative) controller**, specifically for depth control [Khoirunnisa et al., 2024]. The PID algorithm runs in Python on the Raspberry Pi. It takes a depth setpoint from the LabVIEW interface and compares it with real-time feedback from the pressure and lidar sensors to calculate an error. This error is fed into the PID algorithm, which computes the necessary control output for the vertical thrusters to maintain the desired depth [Khoirunnisa et al., 2024].

3.3 System Modeling

The paper includes a detailed PID simulation to determine the optimal gains for the depth controller. The results for various Kp, Ki, and Kd values are presented, analyzing performance metrics such as rise time, settling time, overshoot, and steady-state error [Khoirunnisa et al., 2024]. The optimal tuning was found to be $K_p = 1.5$, $K_i = 0.8$, and $K_d = 0.4$ [Khoirunnisa et al., 2024]. The paper also provides the relevant physics equations for buoyancy, hydrostatic pressure, and thruster angle calculation [Khoirunnisa et al., 2024].

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DESIGN, CONSTRUCTION AND CONTROL OF A REMOTELY OPERATED VEHICLE (ROV)

Team: Alireza Marzbanrad, Jalil Sharafi, Mohammad Eghtesad, Reza Kamali **Date:** August 14, 2025**Cite:** [Marzbanrad et al., 2011]

Abstract

This paper reports on the design, construction, and control of "Ariana-I," an educational and experimental ROV built to serve as a test-bed for advanced control and underwater navigation studies [Marzbanrad et al., 2011]. A secondary goal is to create a prototype for visual inspection of submarine pipelines. It is a large ROV (130kg) with six degrees-of-freedom actuation and is equipped with a comprehensive sensor suite for autonomous or manual operation [Marzbanrad et al., 2011].

1 Design Choices and Architecture

1.1 Materials

The main frame and thruster chassis are made from **ABS plate**, chosen for its near-neutral density and non-magnetic properties [?]. The battery and electronics case is also made of ABS, but features a **bronze** head cover selected for its high thermal conductivity to dissipate heat from the electronics [?]. The buoyancy system consists of tanks made from **PVC plates and pipes** [?].

1.2 Waterproofing and Chassis Design

The chassis is a large open-frame design ($130 \times 100 \times 65$ cm) [?]. Waterproofing for the main electronics and batteries is achieved with a sealed ABS box that uses O-rings between its sections [?]. The thrusters, which are modified sea-scooters, are individually waterproofed [?]. The design prioritizes passive stability by placing the center of buoyancy above the center of gravity, with a target meta-centric height of 0.3m [?]. The buoyancy system is modular, allowing weights and buoyant elements to be added or moved to fine-tune stability [?].

1.3 Propeller Location and Prop Design Choice

Ariana-I uses six thrusters to achieve full six-degrees-of-freedom actuation [?]. The configuration is: two thrusters aligned with the X-axis for surge and yaw; two thrusters aligned with the Y-axis for sway and roll; and two thrusters aligned with the Z-axis for heave and pitch [?]. This vectored arrangement was chosen to overcome the stability limitations of simpler 3-thruster designs and provide full control over all motions [?].

2 Hardware and Software

2.1 Chosen Propeller Motors and Other Sensors

The thrusters are modified **sea-scooters**, each using an 80-watt DC motor with a maximum speed of 400 RPM [?, ?]. The sensor suite includes: a Type 691 pressure transmitter for depth; a 3-axis ADXL335 accelerometer; a 2-axis Turck inclinometer for roll and pitch; and an HMR3300 module for orientation, attitude, and heading [?]. Three water leakage sensors are also installed for safety [?]. A video camera provides visual feedback [?].

2.2 Chosen Control Hardware

The onboard autopilot is based on an **Atmel AVR microcontroller** [?]. This main controller interfaces with all sensors and motor drivers. An **ADUC8041 microcontroller** is used as a dedicated interface for the accelerometer and inclinometer sensors, processing their data before sending it to the main AVR controller [?]. Motor control is handled by three **Sabertooth dual-motor drivers** [?]. Power is supplied by six 24V/6Ah sealed lead-acid batteries [?].

2.3 Chosen Interfacing Architecture

The system architecture supports both autonomous and manual control. Onboard, the AVR microcontroller gathers data from all sensors and can run closed-loop control algorithms for the autopilot [?]. This onboard system communicates with a Surface Control Console (SCC), which is a laptop, via a tether. The SCC runs a graphical user interface for monitoring and high-level command [?]. Video is converted to Ethernet and sent over the tether, while control commands and sensor data are transmitted over an RS485 bus [?].

3 Control Systems and System Modeling

3.1 ROV Communication Method

Control commands and sensor feedback are transferred between the ROV and the Surface Control Console (SCC) over an **RS485 bus** through the tether cable [?]. Video signals are converted to **Ethernet** and transmitted through the same multi-core cable [?]. Internally, the main AVR controller communicates with sensor modules via RS232 links [?].

3.2 Control Architecture

The ROV can be operated manually from the SCC or autonomously via the onboard autopilot [?]. The paper focuses on a **PID-type controller** for heading (yaw) angle regulation [?]. The control loop can be run either on the onboard AVR microcontroller or on the SCC, which allows for real-time tuning and testing of different control schemes without modifying the onboard firmware [?]. Simple PI controllers are noted as sufficient for improving pitch and roll stability [?].

3.3 System Modeling

The paper provides a detailed 6-DOF dynamic equation of motion for the ROV, including terms for rigid-body mass (M_{RB}), added mass (M_A), Coriolis forces ($C(v)$), damping ($D(v)$), and restoring forces ($g(\eta)$) [?]. The rigid-body inertia matrix (M_{RB}) and the restoring forces vector ($g(\eta)$) were calculated using the vehicle's model in Autodesk Inventor software [?].

Design and Analysis of Underwater Remotely Operated Vehicle

Team: Aaditya Kenge, Ankush Mali **Date:** August 14, 2025**Cite:** [Kenge and Mali, 2019]

Abstract

The purpose of this project was to design and analyze a cost-effective, handy, and self-intelligent Remotely Operated Vehicle (ROV) for underwater exploration, surveillance, and data collection [?]. The ROV is intended for tasks such as measuring the depth of dams and rivers, assessing water quality, and capturing high-quality video of underwater environments while being able to navigate around obstacles [?]. The design was validated through Finite Element Analysis using ANSYS [?].

1.1 Materials

After comparing several materials (including Stainless Steel, Aluminum, and Titanium) based on their factor of safety at various depths, **PVC SCHEDULE 80** was selected for the main body (hull) of the ROV [?]. This material was chosen because it is rust-proof, has a high factor of safety at the target depths, and meets cost and availability constraints [?]. Its properties include a compressive strength of 62.05 MPa and a tensile strength of 48.26 MPa [?].

1.2 Waterproofing and Chassis Design

The main body is a cylindrical, bullet-shaped pressure hull designed to house all internal components [?]. It features a transparent glass front for the camera and focus light, with the rest of the body being opaque PVC Schedule 80 [?]. An integral stand is part of the main body design to keep it stable on the ground [?]. Waterproofing is inherent to the pressure hull design, which was validated against buckling failure for an operating depth of 50m [?].

1.3 Propeller Location and Prop Design Choice

The design specifies five thrusters to provide multi-degree-of-freedom propulsion [?]. Three thrusters are oriented vertically, and two are oriented horizontally [?]. This configuration is intended to provide robust control over the vehicle's movement. The thrusters are directly coupled to the main body, and stability is managed by ensuring the vehicle's center of gravity is located approximately at the center of the hull [?].

2.1 Chosen Propeller Motors and Other Sensors

The chosen thrusters are **T100 thrusters**, which can provide a maximum forward thrust of 2.36 Kgf and operate on 12V [?]. The sensor suite is designed for environmental monitoring and includes a real-time camera, a depth sensor, a water quality detector (PH sensor), a pressure sensor, and an IR (Infra-Red) sensor for obstacle detection [?].

2.2 Chosen Control Hardware

This topic was not discussed in this design solution. The paper focuses on the mechanical design and structural analysis of the ROV and does not specify the microcontrollers, motor drivers, or other control hardware.

2.3 Chosen Interfacing Architecture

This topic was not discussed in this design solution. The paper does not provide details on the electronics, software, or the interface between the operator and the ROV. It only mentions that the vehicle is powered by 12V DC [?].

3.1 ROV Communication Method

This topic was not discussed in this design solution. The paper does not specify whether the ROV uses a tether or wireless communication.

3.2 Control Architecture

This topic was not discussed in this design solution. The paper mentions that the ROV is "self-intelligent" and can tackle obstacles, implying some level of autonomous control, but no details of the control architecture or algorithms are provided [**?**].

3.3 System Modeling

The paper presents a detailed structural and mechanical modeling of the ROV. The dimensions (Diameter = 0.168 m, length = 0.4 m, thickness = 15 mm) were used to calculate the induced water pressure at a depth of 50m (0.59 MPa) [**?**, **?**]. The design was checked for external pressure (buckling failure) using the formula $P_c = 3EI/r^3$, which yielded a critical pressure of 3.99 MPa, confirming the design is safe [**?**]. Furthermore, the 3D model was tested using **ANSYS (Static Structural)**, which provided results for equivalent stress, total deformation, and buckling deformation, all of which were within acceptable limits [**?**].

Preliminary Engineering Implementation on Multisensory Underwater Remotely Operated Vehicle (ROV) for Oil Spills Surveillance

Team: F. Qasem, T. B. Susilo, S. Said, Z. Alarbash, et al. **Date:** August 14, 2025**Cite:** [Qasem et al., 2019]

Abstract

This paper proposes an engineering implementation of an **OpenROV v2.8**-based system for oil spill monitoring and detection [Qasem et al., 2019]. The purpose is to create a multisensory ROV that can monitor water quality parameters indicative of oil contamination and use image processing to visually identify oil spills. The system integrates environmental sensors with the standard OpenROV platform [**?**].

1.1 Materials

The ROV itself is based on the **OpenROV v2.8 kit**, which typically uses laser-cut acrylic and 3D-printed parts for its frame and a cast acrylic tube for the main electronics enclosure [Qasem et al., 2019]. The thruster motors were coated with a **silicone-based lubrication** before submersion as a corrosion-proofing measure [Qasem et al., 2019]. A custom 3D-printed gripper was also added [Qasem et al., 2019].

1.2 Waterproofing and Chassis Design

The design uses the standard OpenROV v2.8 chassis, which is a well-tested, neutrally buoyant, and highly maneuverable platform [Qasem et al., 2019]. It measures $30cm \times 20cm \times 15cm$ and weighs 2.6kg [Qasem et al., 2019]. Waterproofing is achieved through the main acrylic tube that houses the core electronics (BBB, Arduino). The environmental sensor payload is mounted externally on the ROV's frame [Qasem et al., 2019].

1.3 Propeller Location and Prop Design Choice

The ROV utilizes the standard OpenROV thruster configuration, which consists of three brushless DC motors [Qasem et al., 2019]. Two motors are mounted horizontally to control the ROV's attitude (surge, sway, yaw), and one motor is mounted vertically to control its elevation (heave) [Qasem et al., 2019]. This configuration provides a speed of approximately 2 knots [Qasem et al., 2019].

2.1 Chosen Propeller Motors and Other Sensors

The ROV is actuated by three **DST-700 brushless DC motors** [Qasem et al., 2019]. The sensor suite is extensive, combining the standard ROV sensors with an additional environmental payload. **ROV Sensors:** An IMU sensor for attitude and altitude, and an HD Camera on a tilt control [Qasem et al., 2019]. **Environmental Sensors:** Four Atlas Scientific sensors to monitor water quality: a temperature sensor (PT-1000), an electrical conductivity (EC) sensor, an oxygen reduction potential (ORP) sensor, and a dissolved oxygen (DO) sensor [Qasem et al., 2019].

2.2 Chosen Control Hardware

The system uses a distributed control architecture. The main ROV control, video, and IMU are handled by a **BeagleBone Black (BBB)** processor, which is standard for the OpenROV kit [Qasem et al., 2019]. The BBB is connected to an **Arduino Mega** board that regulates the tilt-controlled camera [Qasem et al., 2019]. The separate environmental sensor payload is managed by a **Raspberry Pi 3**, chosen for its versatile features and integrated wireless capabilities [Qasem et al., 2019].

2.3 Chosen Interfacing Architecture

The architecture separates the ROV control from the environmental monitoring. The ground station consists of a portable computer and a joystick [Qasem et al., 2019]. The computer communicates with the ROV's BBB via a wired tether for manual control and live video feed [Qasem et al., 2019]. In parallel, the Raspberry Pi 3 collects data from the four environmental sensors and transmits it wirelessly to the ground station computer for logging and analysis [Qasem et al., 2019].

3.1 ROV Communication Method

The system uses a hybrid communication approach. A **wired connection (tether)** is used between the ground station and the BeagleBone Black for robust, low-latency control of the ROV and for receiving the live video feed [Qasem et al., 2019]. A **wireless connection (802.11n Wi-Fi)** is used between the Raspberry Pi (managing the environmental sensors) and the ground station to transmit sensor data [Qasem et al., 2019].

3.2 Control Architecture

The ROV is controlled manually using a joystick connected to the ground station computer [Qasem et al., 2019]. The software focus of this project is on surveillance, not vehicle control. The key software component is a **binary difference image processing algorithm** running in MATLAB on the ground station computer [Qasem et al., 2019]. This algorithm processes the incoming video feed to detect motion and identify potential oil spills by comparing consecutive frames and applying a threshold [Qasem et al., 2019].

3.3 System Modeling

This topic was not discussed in this design solution. The paper focuses on the hardware implementation and experimental validation of the sensor and image processing systems rather than the dynamic modeling of the ROV.

Design and Development of Autonomous and Unmanned Vehicles for Submarine Applications

Team: B. Swapna et al. **Date:** August 14, 2025**Cite:** [Swapna et al., 2024]

Abstract

The purpose of this project is to detail the design and implementation of a miniature Autonomous Underwater Vehicle (AUV). This vehicle serves as a low-cost, small-scale testbed platform for research in underwater technologies, particularly for surface water environments. The design features a fixed mechanical body and a modular electronic system, which allows for the development and testing of various control strategies [Swapna et al., 2024]. The AUV is intended to perform tasks such as navigating, detecting objects and sounds, and processing images [Swapna et al., 2024].

1 Design Choices and Architecture

1.1 Materials

The paper does not specify the materials used for the construction of the AUV's chassis or body. It is mentioned that the prototype was developed using SolidWorks for its design, but no details on the physical materials are provided [Swapna et al., 2024].

1.2 Waterproofing and Chassis Design

The paper states that the AUV has a fixed mechanical system and body, designed in SolidWorks [Swapna et al., 2024]. While specific waterproofing methods for the chassis are not detailed, some components selected are inherently waterproof. For instance, the pressure sensor is described as waterproof and ready to install, and the Blue Robotics Newton Gripper is rated for 300m depth [Swapna et al., 2024]. However, the overall waterproofing strategy for the main electronics enclosures and the chassis itself is not discussed.

1.3 Propeller Location and Prop Design Choice

The AUV is equipped with six T200 thrusters [Swapna et al., 2024]. The thrusters are arranged to provide control for both horizontal and vertical movements. The control system diagrams indicate dedicated thrusters for vertical motion (v1, v2) and horizontal/sway motion (H1, H2, and a sway thruster) [Swapna et al., 2024]. The T200 thruster was selected for its patented flooded motor design, which offers high power and efficiency in a compact form factor [Swapna et al., 2024]. The exact configuration and placement of the six thrusters on the AUV frame are not explicitly detailed in the text or diagrams.

2 Hardware and Software

2.1 Chosen Propeller Motors and Other Sensors

Propeller Motors: The design uses T200 thrusters, which are popular for their power, efficiency, and compact, flooded motor design [Swapna et al., 2024].
Sensors:

- **Pressure Sensor:** A waterproof pressure sensor with a 30 Bar (300m depth) rating and a 2mm depth resolution is used for depth feedback [Swapna et al., 2024].
- **Sonar:** Two Ping single-beam echo sounders are utilized. These have a 50-meter range and a 30-degree beam width, and are mounted on the sides of the AUV to measure distances for obstacle avoidance and navigation [Swapna et al., 2024].

- **IMU:** An MPU-9250 is used, which has a 16-bit register for its sensors and provides attitude information. The paper notes the need to calibrate the magnetometer to compensate for magnetic declination [Swapna et al., 2024].
- **Camera:** A Pixy2 camera is integrated for computer-aided visual recognition, allowing the AUV to detect colors and lines for tasks like object identification and line following [Swapna et al., 2024].
- **Gripper:** A Blue Robotics Newton Subsea Gripper, rated to 300m, is included to allow the vehicle to interact with objects [Swapna et al., 2024].

2.2 Chosen Control Hardware

The control hardware is built around a master-slave microcontroller architecture.

- **Master Controller:** An Arduino Mega 2560, based on the ATmega2560, serves as the master controller. It is responsible for managing the horizontal thrusters and all the main sensors, including the sonar, IMU, and gripper [Swapna et al., 2024].
- **Slave Controller:** An Arduino Uno acts as the slave controller, with its sole purpose being to control the vertical thrusters based on commands from the master controller [Swapna et al., 2024].

2.3 Chosen Interfacing Architecture

The system employs a distributed, master-slave interfacing architecture. The Arduino Mega (master) and Arduino Uno (slave) are at the core of this design [Swapna et al., 2024]. The master Arduino Mega interfaces directly with the suite of sensors (sonar, IMU, depth sensor, gripper) and controls the horizontal thrusters. It communicates with the Arduino Uno, which in turn drives the vertical thrusters. The block diagrams illustrate this separation of tasks, where the master handles higher-level logic and horizontal control, while delegating the vertical control to the slave, creating a modular system [Swapna et al., 2024].

3 Control Systems and System Modeling

3.1 ROV Communication Method

This topic was not discussed in this design solution. The paper focuses on the design of an Autonomous Underwater Vehicle (AUV) and does not describe any communication method, such as a tether or wireless link, to a human operator or surface station. The internal communication between the master and slave Arduino controllers is shown but the protocol (e.g., UART, I2C) is not specified [Swapna et al., 2024].

3.2 Control Architecture

The control architecture is based on feedback loops implemented across the master-slave microcontroller system. The paper presents this through block diagrams rather than complex control theory [Swapna et al., 2024].

- **Depth Control:** The slave Arduino Uno manages depth. It receives data from the depth sensor and uses a feedback controller to adjust the vertical thrusters (V1, V2) to maintain a set depth [Swapna et al., 2024].
- **Sway Control:** The master Arduino Mega controls sway. It uses feedback from the two side-mounted sonar sensors to maintain a certain distance from lateral objects or walls, adjusting the sway thrusters accordingly [Swapna et al., 2024].
- **Horizontal Control:** The master controller also manages the horizontal thrusters (H1, H2) for forward motion and turning [Swapna et al., 2024].

3.3 System Modeling

This topic was not discussed in this design solution. The paper focuses on the hardware components, system architecture, and functional block diagrams for control. It does not present any mathematical or physics-based dynamic modeling of the AUV. While a CAD model was created in SolidWorks, no simulations or analyses based on this model are presented [Swapna et al., 2024].

Development of Remotely Operated Underwater Vehicle and Applications to the Sea

Team: Ikuo Yamamoto, Akihiro Morinaga, Koki Ura **Date:** August 14, 2025**Cite:** [Yamamoto et al., 2019]

Abstract

The purpose of this Remotely Operated Vehicle (ROV) is to provide a high-mobility, portable, and practical solution for the underwater observation and inspection of offshore structures. This includes monitoring facilities such as ports, dams, and renewable energy installations for degradation, cracks, and other damage. The design emphasizes being small-scale, lightweight, and low-cost to serve as a safer and more efficient alternative to human divers.

1 Design Choices and Architecture

1.1 Materials

The main frame of the ROV is constructed from impact-resistant polyvinyl chloride (PVC) pipe, chosen for its durability and contribution to the vehicle's buoyancy structure. A key feature is a moving weight adjustment system, which is manufactured using a 3D printer and installed within the lower pipes of the frame to manage trim. To prevent the tether from impacting vehicle dynamics, floating buoyant material is attached at approximately one-meter intervals along its length.

1.2 Waterproofing and Chassis Design

The chassis was designed using CAD and is based on a unique "principle of float and weight". The upper frame is designed to act as a float, while the lower frame acts as a weight, creating a well-balanced body that is stable even without active thrust. The main electronics, including the control board, power converters, and monitor, are housed in a portable "base station trunk case", which is not submerged. The tether connecting the base station to the ROV is described as waterproof and pressure-tight. However, the paper does not provide specific details on the waterproofing methods used for the onboard components like motors, camera, or lighting.

1.3 Propeller Location and Prop Design Choice

The ROV is equipped with five thruster units. The paper specifies that these allow for motion in multiple directions, including forward, back, side-to-side, rotation, surfacing, and diving, with side-to-side movement made possible by a dedicated side propeller. The specific arrangement and angles of the five thrusters on the frame are not detailed in the paper. Furthermore, the design choices for the propellers themselves, such as diameter, pitch, or blade design, were not discussed.

2 Hardware and Software

2.1 Chosen Propeller Motors and Other Sensors

The propulsion system uses five Mayfair Marine Motor Cartridge units, which operate at 48V and draw between 2-4A. The primary sensor for its observation task is a GoPro HD HERO2 camera, providing a Full HD video stream (1920x1080px at 30 fps) with a wide 170-degree viewing angle. For illumination in dark environments, the ROV is fitted with four powerful Super-Luminosity LED arrays, each capable of producing 14,400 lumens. The paper does not mention the inclusion of other common ROV sensors, such as an Inertial Measurement Unit (IMU) or a depth sensor.

2.2 Chosen Control Hardware

The control system is centered around an Arduino control board, which is integrated into a microcomputer-based control support system. This board is located within the base station trunk case, not on the vehicle itself. The base station also contains the necessary power electronics, including AC-DC converters to step down power from the generator, FETs, and a switching circuit to drive the motors. A dedicated LED dimming control circuit is used to manage the brightness of the lights. The entire system is powered in the field by a 900W GAS engine generator for portability.

2.3 Chosen Interfacing Architecture

The operator uses a joystick which interfaces with the Arduino control board in the base station. The control method is Pulse Width Modulation (PWM) for motor power control. A software program on the control microcomputer interprets the joystick inputs and automatically distributes PWM signals to the five motors to achieve the desired motion. Video from the ROV's camera is transmitted through the tether to a monitor integrated into the portable base station, allowing for real-time visual feedback. All power and data signals are bundled into a single wire cable that connects the base station to the ROV.

3 Control Systems and System Modeling

3.1 ROV Communication Method

All communication between the operator's base station and the ROV is conducted through a physical tether. This "wire cable" is a bundled unit containing both power and signal wires. The operational length of the cable is up to 100 meters, allowing the ROV to work at significant distances from the surface-based operator. This wired approach ensures a reliable, high-bandwidth link for video and control signals.

3.2 Control Architecture

The vehicle is operated via a proportional control system, where joystick inputs are translated into corresponding thruster outputs. The control architecture is designed to be user-friendly, with a microcomputer (Arduino) processing the operator's commands. This computer runs a program that embodies the "operation logistics by a skilled operator," effectively automating the complex task of distributing power to the different thrusters. This allows an operator to control the vehicle effectively without needing specialized training or advanced piloting techniques.

3.3 System Modeling

This topic was not discussed in this design solution. The paper focuses on the physical design, system architecture, and practical experimental validation of the ROV, rather than the development of mathematical or simulation-based system models.

Design of a Cost-effective Autonomous Underwater Vehicle

Team: Michael C. Fowler, Terianne L. Bolding, Kyle M. Hebert, Frank Ducrest, Ashok Kumar **Date:** August 14, 2025**Cite:** [Fowler et al., 2016]

Abstract

The primary goal of this project was to design and build an economical autonomous underwater vehicle (AUV) to address the high cost of commercially available systems. The AUV is intended to be a functional, small-scale platform for approximately $400, with the potential to be scaled up for more complex tasks. The design aims to make underwater robotics more accessible for educational institutions, companies wanting to deploy fleets of AUVs, and a new market of hobbyists for applications like underwater photography and filmmaking. The project focused on using simple, low-cost solutions to complex problems, such as modifying non-traditional components for use in robotics.

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1 Design Choices and Architecture

1.1 Materials

The main structure of the AUV is constructed from schedule-40 PVC pipe segments with a diameter of 1.25 inches. These segments are connected using PVC elbows, t-sections, and 4-way connectors, allowing for easy disassembly. The central electronics housing is a larger 4-inch diameter PVC pipe. Internally, the electronics are mounted on a board made from poplar wood, which is cut to fit inside the housing. This choice of materials was driven by the project's core goal of keeping costs to a minimum.

1.2 Waterproofing and Chassis Design

The chassis has a simple box-like shape, designed to position the motors far from the center of mass to provide adequate torque for turning. The main electronics are housed within a 4-inch diameter PVC pipe. One end of this pipe is permanently sealed with a PVC end cap and epoxy rated to 4400 psi. To allow for external wiring, a 1.5-inch sewage plug was drilled and sealed into this end cap with the same epoxy. Wires have a small segment of their insulation jacket removed and are sealed within this plug with epoxy to prevent water ingress. The other end of the pipe is sealed with a removable plug that uses an O-ring, allowing access to the internal electronics. Initial testing revealed a leak at this plug, which was resolved by reshaping the pipe's edge to better align with the O-ring.

1.3 Propeller Location and Prop Design Choice

The propulsion system consists of three modified 12V bilge pumps. The modifications involved removing the top half of the pump assembly and attaching a 2-inch propeller directly to the drive shaft. The use of bilge pumps was a key cost-saving measure compared to expensive waterproof servos or dedicated thrusters. Two motors are located on the port and starboard sides for forward propulsion and turning, while a third, centrally-located motor is used for depth control. The box-like frame allows these motors to be placed strategically to exert the necessary torque on the vehicle.

2 Hardware and Software

2.1 Chosen Propeller Motors and Other Sensors

Motors: The AUV uses three 12V bilge pumps, rated to pull 10 amps at maximum power, as its thrusters.
Sensors:

- **Depth Sensor:** A differential pressure sensor is used to determine depth. One port is sealed at one atmosphere, allowing the sensor to measure the differential pressure up to 500kPa (approx. 5 atmospheres).

- **Sonar Sensor:** A JSN-SR04T water-resistant sonar sensor is utilized for distance measurement, with a stated range of up to 4.5 meters.
- **Temperature Sensor:** A TMP36 temperature sensor is integrated onto the electronics board to monitor the internal temperature of the electronics housing and prevent overheating.
- **RF Receiver:** A TLP/RLP 434A model receiver is used for surface communication.

2.2 Chosen Control Hardware

The central controller for the AUV is a **BeagleBone Black** microcontroller. It interfaces with a **Rover 5 Motor Driver Board** to control the bilge pump motors. The system is powered by a **12V Lithium Polymer battery** with a capacity of 71-watt hours. Two voltage regulators are used to step down the battery's voltage to appropriate levels for the BeagleBone Black and the motor controller. All electronics are mounted on a poplar wood board that slides into the main housing.

2.3 Chosen Interfacing Architecture

The BeagleBone Black's GPIO pins are connected to the various sensors and the Rover 5 Motor Driver Board. For each motor channel, the BeagleBone Black sends two signals to the motor driver: a direction pin to set the rotation direction and a Pulse Width Modulation (PWM) pin to control the motor's speed. External wiring from the motors and sensors passes through the sealed sewage plug and connects to a 20-pin female connector inside the main tube, which then interfaces with the electronics board. A voltage divider circuit was required for the depth sensor, as its output voltage could exceed the 1.8V limit of the BeagleBone's ADC inputs.

3 Control Systems and System Modeling

3.1 ROV Communication Method

The AUV utilizes a TLP/RLP 434A model RF transmitter/receiver pair for communication. The designers acknowledge that these radio waves do not reliably penetrate water. Therefore, this communication method is intended to be used only when the vehicle is surfaced, allowing an operator to send instructions or new mission parameters before it submerges. Tests involved sending unique bit signatures to turn LEDs on and off, which was deemed sufficient for their purposes.

3.2 Control Architecture

The control software is under development, with the main AI loop being written in C for versatility. The basic motor control functions, such as speed and direction, are implemented in JavaScript using the 'bonescript' library native to the BeagleBone Black. Depth control is achieved through a simple feedback loop where the depth sensor reading is compared to a set depth, and the center motor is activated to move the AUV up or down accordingly. A safety protocol is included where the forward motors shut down if the internal temperature sensor detects overheating, causing the AUV to surface. Future work aims to implement more advanced AI for obstacle avoidance and tracking a diver using light detection.

3.3 System Modeling

This topic was not discussed in detail in the paper. The design process was largely empirical, focusing on practical testing and calibration rather than formal mathematical modeling. For instance, the depth sensor was calibrated by lowering the AUV in a pool and recording the voltage output at different depths, from which they calculated a sensitivity of 269 mV per foot. However, a comprehensive hydrodynamic or kinematic model of the vehicle was not presented.

Small Cluster Underwater Robot design with Variable Pitch Propeller

Team: Aibin Zhu, Jiyuan Song, Ying Li, Mengke Wu and Xiaodong Zhang **Date:** August 14, 2025**Cite:** [Zhu et al., 2018]

Abstract

The purpose of this design is to create a compact, flexible, and highly responsive underwater robot that overcomes the bulkiness and complexity of traditional multi-thruster ROVs. This is achieved through an innovative variable-pitch propeller system where three propellers are driven by a single, common motor. The thrust of each propeller is managed by individually controlling its pitch via a servo. This approach allows for rapid changes in thrust magnitude and direction, enhancing maneuverability. The design also incorporates a retractable float that is separable from the main body, which serves as a communication relay to the ground station and assists in underwater positioning.

1 Design Choices and Architecture

1.1 Materials

The prototype was constructed using materials selected to facilitate ease of production and function. The main shell components are made from **acrylic** and **photosensitive resin**. Internally, the power transmission utilises **nylon** bevel gears. For waterproofing the dynamic drive shafts, the mechanical seals feature **graphite-ceramic** end friction faces.

1.2 Waterproofing and Chassis Design

The chassis is a segmented capsule design, consisting of five sections to house the various modules. The overall shape is smooth to improve hydrodynamics. The structure is designed to be neutrally buoyant in water, simplifying attitude control. The five sections contain: 1) image acquisition, 2) power and control, 3) the core transmission, 4) a cable retractable device, and 5) a separable float. The overall dimensions are 240 mm in length, 120 mm in height, with a cylinder diameter of 80 mm, and it weighs 900g in air. Waterproofing is achieved using several methods: **O-rings** are used to seal the static joints between each of the five hull sections. A **mechanical seal** with an inner diameter of 3mm provides a dynamic seal for the rotating propeller shafts. For the push-rod that controls the propeller pitch, a flexible **tubular waterproof organ** seals the axial movement.

1.3 Propeller Location and Prop Design Choice

The ROV is equipped with three propellers arranged in an orthogonal configuration: one oriented vertically and two horizontally. The horizontal propellers are separated by a center distance of 156 mm. The core design innovation is the use of variable-pitch propellers, where all three propellers are driven by a **single common brushless motor**. While the motor provides constant rotational speed, the thrust from each 60 mm diameter propeller is independently controlled by altering its blade pitch using a dedicated servo motor. This allows for rapid control over the robot's movement and is intended to create a more compact and flexible system than conventional designs that use multiple independent thruster units. The two horizontal propellers rotate in opposite directions to counteract torque, providing stability during horizontal movements.

2 Hardware and Software

2.1 Chosen Propeller Motors and Other Sensors

The propulsion system is driven by a single **brushless motor** that rotates all three propellers. The pitch of each propeller is independently actuated by a dedicated **servo motor**. A separate mini **DC gear motor** is used to operate the cable winding mechanism for the float. The sensor suite includes: a forward-facing **camera** with an **LED** for visual data acquisition, a **depth sensor**, a **gyroscope**, and an **Inertial Measurement Unit (IMU)** for attitude and motion data. For positioning, a **GPS** module is located in the surface float, and two **encoders** are integrated into the float's base to measure the angle of the tether cable.

2.2 Chosen Control Hardware

The control system is based on an embedded platform centered around a main microcontroller, the **STM32F103**. This main controller handles signal processing, generates the PWM signals to drive the brushless motor and the three servos, and manages data communication. A secondary **sensory microcontroller** is used to aggregate data from the onboard sensors (GPS, encoders, depth sensor, gyroscope) and forwards this information to the main controller. A remote **control box** with a screen serves as the human-machine interface for manual control and monitoring.

2.3 Chosen Interfacing Architecture

The interfacing architecture is hierarchical. The operator uses a remote **control box** that communicates wirelessly with the robot's surface float via an **ESP8266** module. This communication unit on the float relays commands to the main **STM32F103** microcontroller through a Universal Synchronous/Asynchronous Receiver/Transmitter (USART) interface. The main controller then communicates with the sensory microcontroller over a second USART bus to receive processed sensor data. The main controller directly interfaces with the actuators, sending **PWM** signals to the brushless motor driver and the three servo motors to control the robot's motion. This setup creates a feedback loop for autonomous control functions.

3 Control Systems and System Modeling

3.1 ROV Communication Method

Communication follows a "robot-floating block-ground station" model. The ROV is physically connected to a separable float via a tether **cable**, which transmits data and power. This float remains on the water's surface while the robot operates underwater. The float is equipped with an **ESP8266** module, which establishes a **wireless link** (via electromagnetic waves) to the ground station control box. This hybrid wired/wireless approach allows the robot to dive while maintaining a stable communication link to the operator.

3.2 Control Architecture

The motion control scheme is based on decoupling rotational power and thrust vectoring. The single brushless motor is typically run at a constant speed, while the robot's movements (e.g., up/down, forward/reverse, turning) are dictated by the pitch angles of the three propellers, which are controlled by their respective servos. Adjusting the servo angles changes the propeller pitch, thereby modulating the thrust's magnitude and direction. For instance, turning on the spot is achieved by setting the pitch angles of the two horizontal propellers to be in the same direction, generating a rotational torque. The control system uses sensor feedback from the IMU, depth sensor, and GPS to either assist a human operator or enable autonomous control modes.

3.3 System Modeling

The paper presents a simplified model for propeller thrust and a geometric model for vehicle positioning. The propeller thrust force (F) is approximated with the empirical equation $F = kD_0 d_l B_0 \omega^2 P$, where thrust is a function of propeller speed (ω) and pitch (d_l). Pitch itself is defined by $d_l = \pi D_0 tan\, \theta$, linking the controllable helix angle (θ) to the final thrust output. This demonstrates that motion is controlled by both motor speed and servo angle. For positioning, a model is used to estimate the robot's underwater coordinates based on the float's location. The robot's position (x_1, y_1, z_1) is calculated using the float's

GPS coordinates (x_0, y_0, z_0), the measured water depth (h), and the cable angles (α, β, γ) measured by encoders, according to the equation: $(x_1, y_1, z_1) = (\frac{h\ cos\ \alpha}{cos\ \gamma} + x_0, \frac{h\ cos\ \beta}{cos\ \gamma} + y_0, h + z_0)$.

Design and Experiments of a low-cost Small Remotely Operated Vehicle System Prototype

Team: Zhanyuan Wang, Dapeng Jiang, Kai Li, Yi Fang, et al. **Date:** August 14, 2025**Cite:** "[Wang et al., 2024]"

Abstract

This paper presents the design, development, and experimental validation of a low-cost small Remotely Operated Vehicle (ROV) system prototype. The system architecture is designed to be expandable and open-source, focusing on a high-quality human-computer interaction (HCI) mechanism. The ROV is capable of fundamental functions like maneuvering and data collection, as well as more advanced tasks such as automatic control (depth and yaw) and image recognition for path-following and crack detection.

1 Design Choices and Architecture

1.1 Materials

The prototype's construction materials were selected to align with the project's goal of creating a low-cost system. The main pressure shell, which houses the electronics, is made of transparent acrylic. This allows for visual inspection of the internal components. The main mechanical structure and frame are constituted by aluminum plates and aluminum profiles. These materials offer a good balance of strength, low weight, and corrosion resistance for operations in freshwater environments like pools and lakes.

1.2 Waterproofing and Chassis Design

The ROV features an open-frame chassis constructed from aluminum profiles. This design supports a central, cylindrical main pressure shell made of acrylic, where all the electronics are housed. The open-frame approach provides structural protection for the central hull and offers ample space for mounting thrusters, sensors, and other external components. The paper does not provide specific details on the waterproofing techniques used for the acrylic hull's end caps or for the cable penetrators.

1.3 Propeller Location and Prop Design Choice

The actuation system is configured to provide high maneuverability. It consists of four vertical thrusters for controlling depth, pitch, and roll. For horizontal plane motion (surge, sway, and yaw), the vehicle uses a vector propulsion mechanism. This mechanism is comprised of a single horizontal thruster mounted on a servo, which allows the direction of the thrust to be changed dynamically. This configuration enables precise control and is particularly important for achieving yaw stability, which is managed by an autonomous control scheme. The specific design of the propellers was not discussed.

2 Hardware and Software

2.1 Chosen Propeller Motors and Other Sensors

The hardware was chosen based on open-source availability and low cost.

- **Motors**: The paper does not specify the model of the thruster motors used. They are controlled via PWM signals generated by the main control board.
- **Sensors**: The sensor suite is designed to provide essential data for navigation and control. It includes:
  - A depth sensor with an IIC interface.

– An attitude sensor with a Serial interface.
– A voltage detection sensor with a Serial interface.
– Two cameras which are treated as network devices.

2.2 Chosen Control Hardware

The control hardware is split between the vehicle and the surface console, with a focus on open-source platforms.

- **Vehicle**: The core control board is an Arduino Mega 2560. This platform was selected for its abundance of digital and analog I/O ports, native support for various communication protocols (SPI, IIC, UART), and its extensive open-source community support. This choice directly supports the project's goals of low cost and ease of development.

- **Surface Console**: The surface console is a standard Windows-based PC, which runs the custom Human-Computer Interface (HCI) software.

2.3 Chosen Interfacing Architecture

The system architecture facilitates communication between the operator, the surface PC, and the vehicle's onboard electronics.

- **Vehicle Software**: The Arduino Mega 2560 runs a core program written in C. Its functions include configuring the hardware, processing sensor data, and sending/receiving data to/from the surface console.

- **Surface Software**: A custom application was developed in C++ using the Qt and OpenCV libraries. This application serves as the HCI, providing widgets for manual control, communication settings, data visualization (including charts and dashboards), and data logging.

- **Communication Link**: The primary link is a neutrally buoyant cable that uses two power line carrier (PLC) modules to establish a network connection. For development convenience, a Bluetooth downloader module is used for wirelessly uploading new programs to the Arduino, improving the efficiency of experiments.

3 Control Systems and System Modeling

3.1 ROV Communication Method

The primary method for ROV operation is a wired network connection established through a neutrally buoyant cable using Power Line Carrier (PLC) modules. This allows for reliable, real-time communication between the surface PC and the ROV. The system is also designed with the capability for wireless communication via a separate module, which would allow it to operate as an AUV for serial data exchange when on the surface.

3.2 Control Architecture

The control system supports both direct manual control and autonomous functions.

- **Manual Control**: An operator uses a joystick connected to the surface PC to perform maneuvers. The HCI software relays these commands to the ROV.

- **Autonomous Control**: The system incorporates autonomous control schemes to assist the operator and perform complex tasks. A PID controller is implemented for fundamental functions like maintaining a constant depth and yaw angle. The PID control law is given as: $\nu(t) = \kappa_0 + \kappa_p \cdot \delta(t) + \kappa_i \cdot \int_0^t \delta(\rho)d\rho + \kappa_d \cdot \frac{d}{dt}\delta(t)$. This foundation is extended for more advanced tasks, such as path-following, which combines the PID controller with a vision-based Line of Sight (LOS) guidance algorithm.

3.3 System Modeling

The paper's focus is on the implementation and experimental validation of the control system rather than on detailed physical system modeling. The modeling is implicit within the control design, where the system's behavior is managed by a PID controller. The performance of this control model was verified through field experiments, with results evaluated against performance indices such as overshooting, settling time, and steady-state error for tasks like depth control, yaw control, and path-following. The paper does not present a hydrodynamic or kinematic model of the vehicle itself.

Designing an Electronic Circuit of the Remotely Operated Underwater Vehicle Based on an Unified Element Base

Team: German A. Galtsov, Sergey Yu. Sakovich **Date:** August 14, 2025**Cite:** "[Galtsov and Sakovich, 2022]"

Abstract

This article presents the project of a small-sized, low-cost Remotely Operated Underwater Vehicle (ROV) designed and developed at SMTU. The design is based on the OpenROV project but aims to significantly reduce cost by using more economical analog components and a unified element base. The paper describes the functional scheme, the electronic motion control circuits, the propulsion system, and the remote control architecture. The goal is to create a simple, modernizable, and publicly accessible ROV suitable for educational and light exploration purposes.

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1 Design Choices and Architecture

1.1 Materials

This topic was not discussed in this design solution. The paper focuses on the electronic circuit and system architecture, using the physical appearance of the OpenROV as a basic prototype for the hull design, but does not specify the materials for construction.

1.2 Waterproofing and Chassis Design

The paper uses the OpenROV as the basic prototype for the vehicle's physical design. This implies an open-frame chassis supporting a central, transparent, watertight cylinder for the electronics. The main design goal was to reduce the cost and complexity of the electronic components housed within this chassis, rather than to redesign the chassis itself. Waterproofing is achieved by the main sealed electronics tube, which is a core feature of the OpenROV platform.

1.3 Propeller Location and Prop Design Choice

The propulsion system was modified from the standard OpenROV design to improve controllability. The OpenROV has two horizontal thrusters and one vertical thruster. This design adds a fourth thruster, resulting in a configuration with:

- Two horizontal thrusters (left and right) for forward/backward movement and turning.
- Two vertical thrusters for up/down movement.

This four-thruster layout provides more balanced control. The thrusters act as propellers to create acceleration and change the vehicle's orientation. The design also includes two servomotors (vertical and horizontal) to control the tilt and pan of the camera, allowing it to monitor objects from different angles.

2 Hardware and Software

2.1 Chosen Propeller Motors and Other Sensors

- **Motors**: The ROV uses four Racerstar BR2212 brushless electric motors, each with a maximum power of 109 watts. These are controlled by four Simonk 30A speed controllers (ESCs).
- **Sensors**:
  - **Vision**: An A4Tech PK-935HL USB webcam is used for the vision system, providing Full HD (1920x1080) resolution. It is mounted on a two-axis servo-driven gimbal. Two ARPL-10W LEDs provide illumination.

- **Navigation**: A 10-DOF Inertial Measurement Unit (IMU) is used for the navigation system. It integrates a three-axis accelerometer, gyroscope, magnetometer, and a barometer.

2.2 Chosen Control Hardware

The control hardware was selected to be low-cost and based on widely available open-source platforms.

- An **Orange Pi One** single-board computer was chosen as the main onboard computer due to its favorable price-to-performance ratio. It handles communication with the surface, processes the camera stream, and sends high-level commands.
- An **Arduino Uno** (based on the ATmega328 microcontroller) is used for low-level control of the motors and servos.
- A **Motor Shield** expansion board is stacked on the Arduino Uno to drive the four brushless motors and two servomotors.

2.3 Chosen Interfacing Architecture

The architecture is a hierarchical system with the Orange Pi acting as the brain and the Arduino as the muscle.

- The operator's PC communicates with the Orange Pi over an Ethernet network.
- The Orange Pi receives commands from the PC and the video stream from the USB webcam. It then sends control instructions to the Arduino Uno.
- The Arduino Uno, via the Motor Shield, generates the necessary PWM signals to control the speed and direction of the four thruster motors and the position of the two camera servos.
- The IMU is connected to the Orange Pi.

The vehicle is powered by an onboard 14V, 20000mAh Lithium battery pack, making it an autonomous power system which reduces tether thickness.

3 Control Systems and System Modeling

3.1 ROV Communication Method

The primary communication method is a wired Ethernet connection via an elastic, near-zero buoyancy optoelectrical cable up to 30m long. This connects the operator's PC on the surface to the onboard Orange Pi computer. This method was chosen because the Orange Pi has a built-in Ethernet controller, eliminating the need for an extra Ethernet shield for the Arduino. The paper also proposes a future modification for wireless operation, using an NRF24L01 radio module to communicate with a surface buoy, which would then relay signals to the ROV.

3.2 Control Architecture

The system is designed for remote operation from a single PC on the shore. Control signals from the operator (e.g., from a keyboard) are sent over the network to the Orange Pi. The Orange Pi processes these signals and commands the Arduino Uno. The Arduino Uno and its Motor Shield then control the actuators (thrusters and servos). The software for the microcontroller is developed using the Arduino IDE, an open-source platform that allows for easy programming and modification. The system relies on a closed-loop control scheme where feedback from sensors (e.g., IMU) can be used to stabilize the vehicle.

3.3 System Modeling

The paper presents functional diagrams and block diagrams of the electronic control circuits rather than a mathematical model of the vehicle's dynamics. It details the motor control loop at a component level. For the brushless motors, it describes the commutation diagram, which requires six transistor switches (MOSFETs) in a bridge scheme to control the three phases of the motor. A functional diagram of the motor control loop shows how a signal from the keyboard is converted to a voltage, compared with feedback from a sensor, amplified, and then supplied to the motor to control its rotation.

Design of a Reconfigurable Autonomous Underwater Vehicle for Offshore Platform Monitoring and Intervention

Team: Marco Pagliai, Alessandro Ridolfi, Jonathan Gelli, Alessia Meschini, Benedetto Allotta **Date:** August 14, 2025**Cite:** "[Pagliai et al., 2018]"

Abstract

This paper presents the design of an innovative, reconfigurable Autonomous Underwater Vehicle (AUV) developed by the University of Florence (DIEF). The vehicle is uniquely designed to switch its physical shape to optimize its performance for different mission phases. In its "closed" configuration, it adopts a hydrodynamic, near-torpedo shape ideal for long-distance transit and surveillance. In its "open" configuration, it transforms into an isotropic and stable platform, suitable for on-site inspection and manipulation, effectively combining the key features of both traditional AUVs and ROVs. The primary application for this vehicle is complex tasks such as monitoring and intervention at offshore platforms.

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1 Design Choices and Architecture

1.1 Materials

The material selection was driven by the demanding operational depth of 1500 m and the need for a lightweight yet strong structure.

- **Main Structure**: The vehicle's body is made from a structural syntactic buoyancy foam from BMTI®, which has a density of $400\ kg/m^3$ and a depth rating of 2000 m. This material provides both buoyancy and structural integrity.
- **Joints and Frame**: The custom-designed actuated joints that enable the vehicle's transformation are made from anodized Aluminium 6062 T6, with Stainless Steel AISI316L used for shafts. The worm drive mechanism within the joint is made of Delrin®.
- **Electronics Housings**: The watertight electronics casings are constructed from cylindrical carbon fiber tubes. Carbon fiber was chosen for its excellent strength-to-weight ratio, which is critical to resist buckling failure at a depth of 1500 m without adding excessive weight.

1.2 Waterproofing and Chassis Design

The vehicle's core design is its reconfigurable chassis, which is based on an articulated frame of 6 joints and 6 structural rods. This allows it to physically transform between two primary configurations:

- **Closed Configuration**: A streamlined, narrow shape (2.2m long x 1m wide) that minimizes drag for efficient long-distance navigation.
- **Open Configuration**: A wide, symmetrical shape (1.7m long x 2.1m wide) that provides high stability and maneuverability for stationary or low-speed inspection and manipulation tasks.

Waterproofing for all electronics is provided by a modular system of cylindrical, watertight casings made of carbon fiber tubes sealed with end caps. A taper joint is used between the caps and tubes to prevent stress concentration. Each module can be put under vacuum to test for and ensure its impermeability before deployment.

1.3 Propeller Location and Prop Design Choice

The propulsion system consists of 8 thrusters, a configuration chosen to ensure the vehicle is fully actuated with control over all 6 Degrees of Freedom (DOF). The layout is dynamic and reconfigures along with the chassis:

- Four thrusters are arranged on the horizontal plane in a vectored configuration, while the other four thrusters provide vertical thrust.
- In the **Open Configuration**, the horizontal thrusters form a vectored layout that is ideal for precise positioning, high maneuverability, and hovering.
- In the **Closed Configuration**, these same four horizontal thrusters are automatically re-aligned to point along the vehicle's longitudinal axis, maximizing their combined thrust for efficient forward propulsion.

2 Hardware and Software

2.1 Chosen Propeller Motors and Other Sensors

- **Motors**: The design specifies the use of **BlueRobotics M200** thrusters. These are three-phase brushless motors designed to operate directly in water without needing an external watertight housing, which simplifies the mechanical design. The same M200 motor model is also used to power the worm drive in the custom actuated joints that facilitate the vehicle's transformation.
- **Sensors**: The vehicle is designed as a modular platform capable of housing a wide range of payloads.
  - **Navigation**: IMU with magnetometer, Depth Sensor, Echo Sounder, GPS, Radio Modem, Wi-Fi, Fibre Optic Gyroscope (FOG), Doppler Velocity Log (DVL), and an Acoustic modem.
  - **Payload**: Frontal and Vertical Cameras, LED Illuminators, Side Scan Sonar (SSS), 2D Forward Looking Sonar (FLS), and a Multibeam sonar.
  - **Internal Health**: Each electronics module is equipped with internal temperature, pressure, and water sensors to monitor its status and detect any failures or leaks.

2.2 Chosen Control Hardware

The electronic architecture is highly modular and distributed. A "core module" contains the main PC and primary navigation sensors. To handle wireless communications (Radio, Wi-Fi, GPS) when the vehicle is on the surface, a separate "antenna module" houses a secondary PC. This separation is a key design choice, intended to isolate sensitive navigation electronics in the core module from the potential electromagnetic noise generated by power systems and high-frequency communication devices. The specific models of the computers are not detailed.

2.3 Chosen Interfacing Architecture

The system architecture is built on a modular design where different functional groups (Core, Antenna, Power, Driver, Battery) are housed in separate, independent watertight casings. The key to this architecture is the communication method:

- All modules are interconnected via an **Ethernet-based local network**. This significantly reduces the complexity of physical wiring between modules and allows for flexible configuration and easy addition of new modules.
- Each module contains a small Ethernet switch and a dedicated "Ethernet ADC/GPIO" board. This board serves a critical function by connecting the module's internal health sensors (temperature, pressure, water) to the network, enabling centralized, real-time monitoring of the entire vehicle's status.

3 Control Systems and System Modeling

3.1 ROV Communication Method

As an AUV, the vehicle is designed for autonomous operation. It is equipped with a comprehensive suite of communication technologies for different situations. When on the surface, it uses its antenna module, which contains a radio modem, Wi-Fi, and GPS, to communicate with a ground station. For underwater data transfer and positioning, it can be equipped with an acoustic modem. The internal communication backbone connecting all onboard modules is a high-speed Ethernet network.

3.2 Control Architecture

The control system is distributed across the modular hardware. The main PC, located in the core module, handles the high-level control tasks, including navigation and mission execution. The dedicated driver module contains the electronics necessary to pilot the motors. While the paper does not specify the control algorithms used, the mechanical design and 8-thruster propulsion system are explicitly configured to provide full 6-DOF actuation, enabling high maneuverability and stable hovering, particularly in the open configuration.

3.3 System Modeling

Significant modeling and analysis were performed on the mechanical and structural aspects of the design.

- **Structural Analysis**: The design of the carbon fiber electronics casings was validated to ensure they could withstand the immense pressure at the 1500 m operational depth. Calculations for buckling strength were performed using the methodology proposed by C.T.F. Ross.

- **Finite Element Method (FEM)**: FEM analysis was used to verify the buckling stability of the tubes (which confirmed a safety factor of 2.367) and to optimize the design of the end caps. This analysis revealed the necessity of a taper joint to mitigate stress concentration at the tube-cap interface.

- **Hydrodynamic Estimation**: A preliminary drag estimation was conducted to forecast the vehicle's performance, including maximum speeds in both configurations and average operational autonomy.

Design of an Autonomous ROV for Marine Growth Inspection and Cleaning

Team: Christian Mai, Malte von Benzon, Fredrik F. Sørensen, et al. **Date:** August 14, 2025**Cite:** "[Mai et al., 2022]"

Abstract

This paper presents the design of a task-specific Remotely Operated Vehicle (ROV) for the automated inspection and cleaning of marine growth from offshore structures. Unlike general-purpose ROVs adapted for this task, this vehicle features a specialized mechanical construction and a flexible software framework to improve efficiency and reduce operational expenditure. The design focuses on creating a lightweight, stable, and powerful platform capable of autonomous operations in the harsh offshore environment of the Danish North Sea. Power and high-pressure water for the cleaning tool are supplied via a tether.

1 Design Choices and Architecture

1.1 Materials

To minimize weight while maintaining structural integrity, aluminum was used for all structural parts of the UUV. The choice of lightweight materials was a key requirement to improve maneuverability and control authority. Other parts, such as the frame, shell, and electric pressure bottles, were specially manufactured for the prototype, while many other components were off-the-shelf to keep construction costs down.

1.2 Waterproofing and Chassis Design

The mechanical design was purpose-built to be optimal for stationary and low-speed cleaning operations.

- **Shape**: A torus (donut) shape was chosen for the chassis. This symmetrical shape was selected because it provides low and consistent hydrodynamic drag regardless of the direction of waves and currents, which simplifies the control system design.

- **Tether Attachment**: The torus shape allows the tether to be attached at the vehicle's center of mass (COM). This is a critical design feature that minimizes the torque disturbances exerted by the tether, which was identified as a significant problem in preliminary studies. A slightly positive buoyant tether is used to ensure it always stays above the UUV.

- **Waterproofing**: The electronics are housed in two separate subsea pressure enclosures. One contains the high-power system (motor drivers, power converters) and the other contains the low-power system (control computer, sensors). This separation improves electromagnetic compatibility (EMC) by physically isolating high-current components from sensitive electronics.

1.3 Propeller Location and Prop Design Choice

The ROV is equipped with eight individual thrusters to ensure it is fully actuated and has high control authority. The layout is symmetrical:

- Four thrusters are arranged for horizontal movement (surge, sway) and yaw. They are placed at a 45-degree angle relative to the forward direction to maximize available thrust in cardinal directions.

- Another four thrusters are placed for vertical movement (heave), roll, and pitch. They are also angled to allow all thrusters to contribute to pitch and roll motions, providing strong attitude control.

2 Hardware and Software

2.1 Chosen Propeller Motors and Other Sensors

The system is equipped for autonomous operations and its specific cleaning task.

- **Motors**: The paper does not specify the model of the thruster motors, but notes that they are driven by ESCs and require a total of at least 6kW of actuation power.
- **Cleaning Tool**: Feasibility studies determined that the most effective tool for removing hard marine growth was water jetting with a single rotating jet nozzle, operating at 500 bar with a flow of 30 L/s. This high power requirement necessitates that the UUV be tethered.
- **Sensors**: The vehicle is designed to be equipped with a suite of commercially available sensors, including sonar, vision-based sensors (IP camera), an Inertial Measurement Unit (IMU), a Doppler Velocity Log (DVL), and internal pressure/temperature sensors.

2.2 Chosen Control Hardware

The onboard control computer was chosen to provide sufficient computational resources to handle control algorithms and sensor processing locally, thereby avoiding latency issues associated with offloading computation to the topside.

- The main control computer is the **Nvidia Jetson TX2i** system-on-module, mounted on a carrier board. This platform was chosen for its powerful CPU, integrated GPU for accelerated algorithms, and a wide range of available communication interfaces (Ethernet, CAN, Serial, etc.).
- A daughterboard (Arduino) is used in the high-power system to interface with the lights and ESCs, communicating with the main computer via a bi-directional serial link.

2.3 Chosen Interfacing Architecture

The architecture is designed for modularity and robustness.

- **Power and Data Separation**: The electrical system is split into two enclosures: a high-power side (for thrusters) and a low-power side (for control and sensors). They are connected by a galvanically isolated serial link to prevent ground loops and noise interference.
- **Communication**: The primary communication protocol is Ethernet, which connects the main control computer to the topside PC, DVL, and cameras. CAN-bus is used for interfacing with sensors like the IMU and pressure sensor.
- **Topside System**: A standard PC running Ubuntu Linux serves as the Human-Machine Interface (HMI). It connects to the UUV via the tether and uses a joystick for manual teleoperation. An adjustable 10kW DC power supply provides power to the UUV.

3 Control Systems and System Modeling

3.1 ROV Communication Method

The ROV is connected to a topside facility via a multi-component tether, which is required to be at least 100m long. The tether delivers high-voltage (360V) DC power for the onboard systems, high-pressure water for the cleaning tool, and an Ethernet connection (>100 Mbit) for data communication and control signals. The tether is designed to have the smallest possible diameter to minimize hydrodynamic drag.

3.2 Control Architecture

The software architecture is built around the **Robot Operating System (ROS)** (specifically, ROS1 Melodic). This was chosen because it is modular, extensible, open-source, and platform-agnostic, meeting all the software requirements. ROS allows for easy integration of off-the-shelf hardware and software packages, which significantly reduced development time. The architecture uses ROS nodes for all major functions, including sensor drivers, control algorithms, and communication. A thruster manager node handles the allocation of forces and torques to the individual thrusters. High-level control algorithms can be prototyped in MATLAB/Simulink and connected to the system using the ROS Toolbox.

3.3 System Modeling

The paper utilizes simulation as a key part of the design and development process. The **Gazebo** robot simulator, along with the **UUV Simulator** plugin, was used for initial design and testing of control and filter algorithms. The UUV Simulator is a critical tool as it adds hydrodynamic and hydrostatic forces into Gazebo's physics engine and provides models for underwater sensors like DVLs and sonars. This allows for realistic testing of algorithms in a simulated 3D world before deployment on the physical prototype. MATLAB and Simulink were also used for control design and hardware-in-the-loop testing, leveraging their specialized toolboxes.

Underwater Robot Design Proposed Method Based on CAD and CFD

Team: Maria Celeste Paredes-Sanchez, Delond Angelo Jimenez-Nixon, José Luis Ordoñez-Avila
Date: August 14, 2025**Cite:** "[Paredes-Sanchez et al., 2022]"

Abstract

This paper presents a comprehensive design methodology for an underwater robot, demonstrating a process that integrates Computer-Aided Design (CAD) and Computational Fluid Dynamics (CFD) to develop a complete hierarchical dynamic model before physical construction. Following this method, a 5-DOF submersible ROV was designed with a mass of 9.17 kg, capable of operating at depths up to 50 m. The design features a hermetic spherical acrylic enclosure for electronics, a styrofoam buoyancy element for equilibrium, and six thrusters. The paper details the calculation of all dynamic model matrices, including inertia, damping, and thruster configuration.

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1 Design Choices and Architecture

1.1 Materials

The materials for the proposed ROV design were chosen for their specific properties to ensure structural integrity and proper buoyancy.

- **Structure**: The support structure is designed to be made from thick glass fiber reinforced plastic (GRP) plates. GRP is a strong, lightweight, and corrosion-resistant material suitable for marine applications.
- **Electronics Enclosure**: A hermetic spherical enclosure made of acrylic is used to protect the electronic components. Acrylic is strong and transparent, allowing for visual inspection. The enclosure is sealed at both ends by 6060-T6 aluminum sealing caps.
- **Buoyancy Element**: To achieve near-neutral buoyancy, a buoyancy element made of extruded polystyrene foam (XPS), commonly known as styrofoam, is added. XPS was chosen for its very low density ($50kg/m^3$ was used in the design), which allows it to increase the vehicle's volume (and thus its buoyant force) without significantly increasing its mass.

1.2 Waterproofing and Chassis Design

The proposed chassis consists of a GRP plate structure which supports the other components. The design is open, allowing easy access to the thrusters and the main electronics enclosure. Waterproofing is centered around the main hermetic acrylic sphere that contains all sensitive electronic components. This sphere is sealed by two aluminum caps. The paper does not specify the exact sealing mechanism (e.g., O-rings) but emphasizes that the enclosure must be hermetic. The overall design was validated through stress tests in SolidWorks to ensure it could withstand the pressure at the maximum operating depth of 50 m.

1.3 Propeller Location and Prop Design Choice

The ROV is designed with six thrusters to provide 5-DOF control (surge, sway, heave, pitch, and yaw). The thruster configuration is as follows:

- Four thrusters are installed horizontally, vectored at a 45-degree angle. This configuration allows for combined surge, sway, and yaw control.
- Two thrusters are installed vertically to control heave and pitch.

This arrangement is designed to provide high maneuverability. The moment arms of each thruster relative to the center of mass were determined from the CAD model and used to derive the thruster configuration matrix for the dynamic model.

2 Hardware and Software

2.1 Chosen Propeller Motors and Other Sensors

This topic was not discussed in this design solution. The paper focuses on the mechanical design and dynamic modeling methodology. It proposes a design that includes sensors, but does not specify the models. The conceptual design includes an IMU, digital compass, depth sensor, temperature sensor, video camera, and a leak sensor. The thruster motor type is also not specified.

2.2 Chosen Control Hardware

This topic was not discussed in this design solution. The paper's scope is the pre-build design phase, focusing on developing the dynamic model that would later be used to design a suitable control system. It does not select or specify any control hardware like microcontrollers or computers.

2.3 Chosen Interfacing Architecture

This topic was not discussed in this design solution. As the paper does not deal with the implementation of the electronics or software, there is no discussion of the interfacing architecture.

3 Control Systems and System Modeling

3.1 ROV Communication Method

This topic was not discussed in this design solution. The paper focuses on the physical design and mathematical modeling of the vehicle itself, not its communication systems.

3.2 Control Architecture

This topic was not discussed in this design solution. The paper's stated goal is to define the dynamic model, which is a necessary prerequisite for the subsequent construction of a suitable control system. It does not propose or implement a control architecture.

3.3 System Modeling

The core contribution of this paper is its detailed, step-by-step system modeling methodology, which aims to create a comprehensive hierarchical dynamic model before building a physical prototype. The process is as follows:

1. **CAD-based Mechanical Design**: A detailed 3D model of the ROV is created in SolidWorks. This provides key parameters for the dynamic model, including the vehicle's mass (m), volume (V), center of gravity, and the rigid-body inertia matrix (M_{RB}).

2. **Stress Tests**: Pressure simulations are performed on the CAD model to validate its structural integrity at the target depth (50 m) and confirm material choices.

3. **Computational Fluid Dynamics (CFD)**: Fluid simulations are run on the CAD model to analyze its hydrodynamic properties. By simulating the vehicle's motion at various velocities, the forces and torques are calculated. A polynomial regression is then used on this data to estimate the linear and quadratic damping coefficients (D_L and D_Q). For example, the drag force in surge was approximated as $f_{rx} = -23.547v_x^2 - 0.5483v_x + 0.0146$.

4. **Analytical Method**: Since no physical prototype exists for experimental testing, the added mass coefficients (M_A) are calculated analytically. The vehicle's complex shape is approximated as an ellipsoid, and standard formulas for this shape are used to estimate the added mass terms.

5. **Hierarchical Dynamic Model**: Finally, all the calculated matrices (M_{RB}, M_A, D_L, D_Q), along with the Coriolis-centripetal matrix ($C(v)$), restoring forces vector ($g(\eta)$), and the thruster configuration matrix (τ), are assembled to form the complete dynamic model of the ROV.

Early Stage Design of a Spherical Underwater Robotic Vehicle

Team: Soheil Zavari, Arttu Heininen, Jussi Aaltonen, Kari T. Koskinen **Date:** August 14, 2025**Cite:** "[Zavari et al., 2016]"

Abstract

This paper presents the early-stage design of a high-performance, spherical autonomous underwater robot developed for the inspection of flooded mines up to 500 meters deep. The paper details the initial mechanical and mechatronic design of the vehicle's subsystems. A key aspect of the work is the analysis of the vehicle's equation of motion, where the hydrodynamic coefficients are addressed. The paper demonstrates that the spherical design simplifies the theoretical determination of the main coefficients of motion due to its symmetry.

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1 Design Choices and Architecture

1.1 Materials

The main hull of the vehicle is specified to be made of Aluminium. This material was likely chosen for its high strength-to-weight ratio, which is essential for withstanding the high pressures at the 500-meter maximum operating depth (approximately 50 bar), while keeping the overall vehicle weight manageable. Other material specifics are not detailed.

1.2 Waterproofing and Chassis Design

The vehicle is designed with a spherical hull, with a maximum diameter of 60 cm. This shape was chosen for several key reasons:

- **Maneuverability**: A sphere is inherently isotropic, which enhances maneuverability and allows thrusters to be easily installed at any point on its surface, which is beneficial for navigating the narrow and constrained channels of a flooded mine.
- **Hydrodynamics**: The spherical profile minimizes hydrodynamic drag, which is advantageous for reducing power consumption during transit.
- **Structural Integrity**: A sphere is the optimal shape for resisting uniform external pressure, which is a critical consideration for a vehicle designed to operate at a depth of 500 meters.

Waterproofing is achieved by the sealed spherical hull. The design also incorporates a ballast system with a 4-liter internal tank located at the bottom of the sphere, with the option for an additional 4-liter external cylindrical tank for long vertical transits.

1.3 Propeller Location and Prop Design Choice

The AUV is equipped with 8 thrusters to provide high maneuverability and control over surge, heave, and yaw. The thruster configuration is a key design feature:

- The thrusters are arranged in two manifolds, one on each side of the sphere.
- Each manifold contains four openings housing two horizontal and two vertical thrusters.
- This symmetrical distribution of the 8 thrusters is a cornerstone of the design, allowing for precise steering control by producing torque to change the vehicle's heading. The horizontal thrusters are positioned to maximize the torque they can generate while maintaining the vehicle's streamlined spherical profile.

2 Hardware and Software

2.1 Chosen Propeller Motors and Other Sensors

- **Motors**: The vehicle uses eight brushless electric motors, each measuring 97mm (D) x 113mm (L) and capable of producing a maximum thrust of 34.3 N at 12V. Each thruster comes with its own speed controller unit housed in a pressure-resistant container and is operated via Pulse Width Modulation (PWM) signals.

- **Sensors**: For the initial phase of low-level control and navigation testing, the vehicle is equipped with:

  – An Inertial Measurement Unit (IMU).
  – A Doppler Velocity Log (DVL) for accurate velocity measurement.
  – A pressure sensor for depth measurement.
  – Leakage and temperature sensors for system safety and health monitoring.

  The full vision system, intended to include sonars and multiple cameras for 3D mapping, is mentioned but is outside the scope of the paper.

2.2 Chosen Control Hardware

A dual-controller architecture is used for the system.

- The **Main Controller** is a fanless, Core i7 dual-core embedded computer (Speedgoat real-time machine). This high-performance unit was chosen for its capability to run multiple software modules with real-time characteristics and to facilitate rapid prototyping. It is equipped with an I/O module for interfacing with analog and digital sensors and is used for data acquisition, numerical computation, and sending commands to the thrusters.

- A secondary **Safety Controller**, an 8-bit Atmel ATmega32HVB microcontroller, is responsible for system safety power management. It can autonomously shut down the power in the event of a leak or if battery levels are too low to safely complete a mission.

2.3 Chosen Interfacing Architecture

The system components are interfaced with the main controller using standard communication protocols.

- The eight thrusters are networked together and communicate with the main controller over an **I2C protocol**. Each thruster is assigned a unique node ID and sends feedback data (pulse count, voltage, temperature, current) at a frequency of 6 Hz.

- The pressure sensor communicates with the main controller via an Analog-to-Digital Converter (ADC) unit over a **serial port**.

- The main controller (Speedgoat machine) acts as a dedicated target computer, allowing control models to be developed on a host computer and then deployed for real-time execution on the hardware.

3 Control Systems and System Modeling

3.1 ROV Communication Method

This topic was not discussed in this design solution. As the vehicle is designed as a fully autonomous AUV for exploring flooded mines, it is implied that it operates without a tether. The paper does not discuss methods for mission programming or data retrieval (e.g., surface communication via Wi-Fi or acoustic modem).

3.2 Control Architecture

The paper focuses on the hardware and dynamic modeling required for control, rather than the control algorithms themselves. The control architecture is built around the Speedgoat real-time machine, which is designed to run real-time applications and execute control models developed on a host computer. The system is designed to control surge, heave, and yaw motions. Pitch and roll are passively stabilized by placing the center of gravity (CG) 10mm below the center of buoyancy (CB).

3.3 System Modeling

A significant portion of the paper is dedicated to establishing the vehicle's dynamic model, which is a crucial step for developing its control system. The equation of motion, $M\dot{V} + C(V)V + D(V)V + g = BT_{thruster}$, is defined. The key advantage of the spherical design is leveraged to simplify the calculation of the model's parameters:

- **Inertia Matrix (M)**: Comprises the rigid-body inertia (M_{RB}) and added mass (M_a). Because the sphere is symmetrical, the off-diagonal terms of the inertia tensor are zero, simplifying the M_{RB} matrix. The added mass terms for a sphere are well-defined in fluid dynamics literature, allowing for a straightforward theoretical calculation of the M_a matrix.
- **Coriolis Matrix (C(V))**: This is also simplified due to the symmetry and the low operational velocities of the vehicle.
- **Damping Matrix (D(V))**: The drag force was calculated theoretically, allowing for the derivation of the quadratic damping coefficients. The linear damping coefficients for rotational motion were also estimated based on established formulas for a rotating sphere.
- **Restoring Forces (g)**: The restoring force vector was calculated based on the offset between the center of gravity and the center of buoyancy.

Design and Control of an Unmanned Underwater Vehicle

Team: Kursad Metehan Gul, Cengizhan Kaya, Aleyna Bektas, Prof. Dr. Zafer Bingul **Date:** August 14, 2025**Cite:** [Gul et al., 2020]

Abstract

This paper presents the mechanical design, mathematical modeling, and control of an Unmanned Underwater Vehicle (UUV) that combines features of both Remotely Operated Vehicles (ROV) and Autonomous Underwater Vehicles (AUV) [Gul et al., 2020]. The vehicle is designed for stable 5-DOF maneuverability, with passive pitch stability. A primary focus of the work is the development of a detailed mathematical model derived from Newton-Euler equations, which is then used to create a closed-loop control system and simulation environment in Matlab/Simulink [Gul et al., 2020].

1 Design Choices and Architecture

1.1 Materials

The paper does not specify the materials used for constructing the vehicle's chassis or the waterproof electronics tubes. The design was rendered in SolidWorks to determine physical properties like mass and inertia [Gul et al., 2020].

1.2 Waterproofing and Chassis Design

The design features two separate waterproof tubes: an upper tube for all electronics except the battery, and a lower tube specifically for the battery [Gul et al., 2020]. Waterproof fittings and connectors are used for all cable penetrations to allow for easy component replacement without compromising the integrity of the main enclosures. A key feature of the chassis design is the deliberate placement of the center of buoyancy above the vehicle's geometric origin and the center of gravity below it. This separation creates a righting moment that provides passive stability in roll and pitch, which simplifies the control system [Gul et al., 2020].

1.3 Propeller Location and Prop Design Choice

The UUV uses a six-thruster configuration to achieve 5-DOF maneuverability (surge, sway, heave, roll, and yaw), with pitch motion being passively stabilized [Gul et al., 2020]. Four horizontal thrusters are positioned at the corners of the vehicle, vectored at 45-degree angles, to provide coupled control of surge, sway, and yaw. Two vertical thrusters are placed centrally to control heave and roll. To achieve balanced force generation, conjugate thrusters (e.g., front-left and front-right) are designed to rotate in opposite directions [Gul et al., 2020].

2 Hardware and Software

2.1 Chosen Propeller Motors and Other Sensors

The paper does not specify the models of the motors or sensors used in the physical construction of the UUV. The control system is described as a closed-loop system that uses sensor feedback, but the specific sensors are not identified [Gul et al., 2020].

2.2 Chosen Control Hardware

The specific control hardware, such as the microcontroller or single-board computer used to run the control algorithms, is not detailed in the paper. The focus is on the theoretical development and simulation of the control system [Gul et al., 2020].

2.3 Chosen Interfacing Architecture

This topic was not discussed in this design solution. The paper focuses on the mathematical modeling and simulation of the vehicle, rather than the physical implementation of its electronic architecture.

3 Control Systems and System Modeling

3.1 ROV Communication Method

The vehicle is designed to have features of both ROVs and AUVs, allowing it to be controlled manually by a remote pilot or to operate autonomously based on its own decision-making [Gul et al., 2020]. The specific communication method (e.g., tether, acoustics) is not specified.

3.2 Control Architecture

A closed-loop control system is employed for both manual and autonomous operating modes [Gul et al., 2020]. The system uses a conventional PID controller for each of the 6 axes of motion. The PID parameters were initially approximated using the Ziegler-Nichols tuning method and then fine-tuned experimentally within the Simulink simulation environment to account for the highly nonlinear dynamics of the system [Gul et al., 2020].

3.3 System Modeling

The paper provides a comprehensive 6-DOF mathematical model of the UUV based on the Newton-Euler formulation. The model is separated into kinematics, which uses Euler angles to describe the vehicle's orientation, and kinetics, which describes the forces and moments acting on the vehicle [Gul et al., 2020]. The kinetic model includes terms for rigid-body dynamics (M_{RB}, C_{RB}), hydrodynamic effects (added mass M_A, added Coriolis C_A, and both linear and quadratic damping $D(v)$), and hydrostatic restoring forces ($g(\eta)$). A detailed thruster model, including a 6x6 thruster configuration matrix (T), is also derived to map individual thruster forces to the net forces and moments on the vehicle body. Parameters for the model were determined from the SolidWorks design (mass, inertia, center of gravity), experimental testing (thruster coefficients), and from literature on similarly shaped vehicles (damping coefficients) [Gul et al., 2020].

Design and Development of a Remotely Operated Underwater Vehicle

Team: Chanin Joochim, Rattanakorn Phadungthin, Sawangtit Srikitsuwan **Date:** August 14, 2025**Cite:** [Joochim et al., 2015]

Abstract

This paper describes the design and development of a small Remotely Operated Underwater Vehicle (ROV) created for underwater exploration in hazardous or difficult-to-reach areas [Joochim et al., 2015]. The vehicle is equipped with sensors, DC brushless motors, and a real-time camera. It is controlled from a base station via a tether, featuring an automated tilt control system for pitch stability and a joystick for manual surge control. The system aims to provide an easy-to-use and accurate platform for underwater observation [Joochim et al., 2015].

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1 Design Choices and Architecture

1.1 Materials

The ROV is constructed using a combination of acrylics and aluminum [Joochim et al., 2015]. These materials were chosen to avoid interference with the onboard magnetic compass. Balancing weights are also added to the structure to enhance its stability in the water [Joochim et al., 2015].

1.2 Waterproofing and Chassis Design

The ROV has a square-shaped structure [Joochim et al., 2015]. All sensitive electronic components, including the microcontroller, sensors, and camera, are housed within a central water leakage protection block. The cable connection junction, identified as a weak point for leaks, is sealed with high-performance silicone paint. The main tether is reinforced with a steel wire to protect it from strain during recovery and from damage due to twisting during movement [Joochim et al., 2015]. Mechanical stability is enhanced by adding balancing weights to counteract the vehicle's natural tendency to float unstably due to trapped air [Joochim et al., 2015].

1.3 Propeller Location and Prop Design Choice

The vehicle employs a six-thruster configuration. Four thrusters are located at the corners to control horizontal plane movements (surge, sway, yaw) [Joochim et al., 2015]. Two thrusters are used for vertical motion (heave). This design was an enhancement of a five-thruster model; an additional vertical thruster was added because experiments showed that a single vertical thruster was insufficient to maintain pitch and roll stability, potentially causing the robot to become unstable or flip upside down [Joochim et al., 2015].

2 Hardware and Software

2.1 Chosen Propeller Motors and Other Sensors

The ROV is propelled by six DC brushless motors, which were chosen for their advantage of being operable in water without requiring additional waterproofing or modification [Joochim et al., 2015]. The sensor suite includes an IMU-GY85 module, which combines an accelerometer, gyroscope, and compass to provide the necessary data for closed-loop attitude control (roll, pitch, and yaw) [Joochim et al., 2015]. A USB OV7670 camera is used to capture images and provide a live video stream to the operator. Additionally, a custom current-checking circuit is installed to monitor the current flow to each motor, which helps in diagnosing motor failures during operation [Joochim et al., 2015].

2.2 Chosen Control Hardware

The core of the onboard control system is an Arduino microcontroller [Joochim et al., 2015]. This board is responsible for reading data from all sensors, interpreting commands received from the base station, and controlling the speed and direction of the six brushless motors [Joochim et al., 2015].

2.3 Chosen Interfacing Architecture

The system architecture connects a joystick to a base station computer, which runs a custom Graphical User Interface (GUI) developed in the Processing programming environment [Joochim et al., 2015]. This computer communicates with the ROV over an Ethernet-based network facilitated by an internet hub on the surface and another hub on the vehicle, connected via the tether. Onboard the ROV, the hub connects to the Arduino microcontroller and the video module. The Arduino interfaces directly with the IMU sensor, the current sensor, and the motor controllers to manage the vehicle's operation [Joochim et al., 2015].

3 Control Systems and System Modeling

3.1 ROV Communication Method

The ROV communicates with the surface base station through a physical underwater cable (tether). The communication protocol is network-based, utilizing internet hubs on both the surface and the ROV to transmit control commands, sensor telemetry, and the live video stream [Joochim et al., 2015].

3.2 Control Architecture

The control is a combination of manual and automated systems. The operator manually controls the ROV's surge and yaw movements using a joystick connected to the base station computer [Joochim et al., 2015]. The command signals are sent to the onboard Arduino via the tether. Simultaneously, the Arduino runs an automated closed-loop control system that uses data from the IMU sensor to maintain the vehicle's stability. A robust PID control loop is noted as being necessary to manage the roll and pitch angles and keep the vehicle level, especially when facing unpredictable underwater currents [Joochim et al., 2015].

3.3 System Modeling

The paper does not present a formal mathematical model of the ROV's dynamics. The control system design is based on the implementation of a PID closed-loop controller using real-time sensor feedback. To determine the necessary vertical thruster force, a calculation based on Archimedes' Principle was performed to find the net buoyant force that the thrusters must overcome to submerge the vehicle. The paper also provides graphical results from experimental tests, showing the IMU sensor data (angular velocity, rotation angle, compass readings) recorded during various maneuvers [Joochim et al., 2015].

Underwater ROV with Fuzzy Logic Motion Control

Team: N.D. Jayasundere and S.H.K.K. Gunawickrama **Date:** August 14, 2025**Cite:** [Jayasundere and Gunawickrama, 2016]

Abstract

This paper details the design and development of a low-cost Remotely Operated Vehicle (ROV) intended for operation in shallow water environments up to 10 meters deep [Jayasundere and Gunawickrama, 2016]. The primary application for this ROV is the observation and monitoring of coral reefs. The project was executed in two phases: the first phase focused on the initial mechanical and electronic design, while the second phase introduced a more sophisticated Fuzzy Logic controller to improve the vehicle's motion control in dynamic ocean conditions [Jayasundere and Gunawickrama, 2016].

1 Design Choices and Architecture

1.1 Materials

The ROV's structure was designed to be assembled from cost-effective and commonly available materials [Jayasundere and Gunawickrama, 2016]. The central housing is a 4-inch diameter DWV (drain, waste, and vent) PVC pipe. The front viewport is a transparent dome made from a clear street lighting lamp shade. Two smaller 2-inch diameter PVC pipes are used as side cylinders for balance and to mount lights and thrusters [Jayasundere and Gunawickrama, 2016]. A stainless steel rim is used to attach the front dome to the central housing [Jayasundere and Gunawickrama, 2016].

1.2 Waterproofing and Chassis Design

The chassis design is based on a main central cylinder that contains the removable electronic bay [Jayasundere and Gunawickrama, 2016]. The front end is fitted with the transparent dome to act as a window for the camera, while the back end is sealed with a PVC end cap [Jayasundere and Gunawickrama, 2016]. The dome is made watertight using a rubber ring seal, a stainless steel rim, and silicone sealant. The two side cylinders, used for balance, are also sealed and house the LED lights and two of the thrusters [Jayasundere and Gunawickrama, 2016].

1.3 Propeller Location and Prop Design Choice

The ROV utilizes a five-thruster system to achieve controlled motion in a three-dimensional coordinate system [Jayasundere and Gunawickrama, 2016]. Two thrusters are mounted horizontally on the back ends of the side PVC pipes to provide forward, backward, and steering (yaw) motions. Three thrusters are mounted vertically: one on the rear of the main housing, and two on the front end of the side balancing pipes. These vertical thrusters provide up-down control, dynamic leveling, and wave effect control. The two front vertical thrusters are tilted to generate horizontal forces to help control against waves [Jayasundere and Gunawickrama, 2016].

2 Hardware and Software

2.1 Chosen Propeller Motors and Other Sensors

The thrusters are five Johnson bilge pump motors, each rated at 500 gph (gallons per hour), drawing 2.5 A at 12 V DC, and equipped with 3-blade propellers [Jayasundere and Gunawickrama, 2016]. The sensor suite is a 10 Degree of Freedom (DOF) Inertial Measurement Unit (IMU) platform, which includes a 3-axis accelerometer (ADXL345), a 3-axis magnetometer (HMC5883L), a 3-axis gyroscope (L3G4200D), and a barometric pressure sensor (BMP085) [Jayasundere and Gunawickrama, 2016]. The vehicle is also equipped with a camera for live video and two LED lamps for illumination [Jayasundere and Gunawickrama, 2016].

2.2 Chosen Control Hardware

The main controlling units of the electronics are a Raspberry Pi microcomputer and an Arduino board [Jayasundere and Gunawickrama, 2016]. The Raspberry Pi serves as the master controlling unit and was initially used for video processing, though this was later offloaded to a dedicated camera module to improve performance. The Arduino plays a key role in interfacing with and controlling the 10 DOF IMU, motor control circuits, LED switching circuits, and the joystick [Jayasundere and Gunawickrama, 2016].

2.3 Chosen Interfacing Architecture

Communication with the ROV is handled via a tethered cable that provides both power and a network link [Jayasundere and Gunawickrama, 2016]. A CAT5e Ethernet cable is used to establish a network connection between a laptop on the surface and the onboard Raspberry Pi, which hosts a web-based control interface [Jayasundere and Gunawickrama, 2016]. The Arduino acts as an intermediary, establishing the communication interface between the Raspberry Pi and all the low-level hardware, including sensors and motor controllers [Jayasundere and Gunawickrama, 2016].

3 Control Systems and System Modeling

3.1 ROV Communication Method

The ROV uses a wired communication system via a tether that runs from the surface to the vehicle [Jayasundere and Gunawickrama, 2016]. This tether carries the necessary power for the ROV's operation and a CAT5e Ethernet cable for network communications between the operator's laptop and the onboard Raspberry Pi [Jayasundere and Gunawickrama, 2016].

3.2 Control Architecture

The ROV is manually controlled by an operator using a joystick and keyboard [Jayasundere and Gunawickrama, 2016]. To improve performance in dynamic conditions, a Fuzzy Logic motion controller was developed and implemented. This is a Multi-Input Multi-Output (MIMO) controller with four distinct sub-controllers for Yaw, Pitch, Roll, and Depth [Jayasundere and Gunawickrama, 2016]. The fuzzy controller uses feedback from the 10 DOF IMU to calculate errors in the ROV's orientation and depth, and then adjusts motor speeds to correct these errors and respond to user commands simultaneously. The Mamdani fuzzy inference method is used for the controller logic [Jayasundere and Gunawickrama, 2016].

3.3 System Modeling

This design does not rely on a traditional mathematical model of the vehicle's dynamics. Instead, it leverages a fuzzy control strategy, which is advantageous because the complete dynamics of the system do not need to be fully known [Jayasundere and Gunawickrama, 2016]. To improve the quality of the sensor data used by the controller, a one-dimensional Kalman filter is applied to the raw outputs from the IMU and pressure sensor. This filtering step minimizes noise and degradation of responsivity. The paper provides the update equations used for this Kalman filter: $p = p + q;$, $k = p/(p + r);$, $x = x + k * (measurement - x);$, $p = (1 - k)^{*}p;$ [Jayasundere and Gunawickrama, 2016].

Underwater survey system of dam embankment by remotely operated vehicle

Team: Hideki Sugimoto, Yoichi Moriya and Tetsuya Ogasawara **Date:** August 14, 2025**Cite:** [Sugimoto et al., 2017]

Abstract

The purpose of this ROV is to conduct efficient and safe inspection and investigation of large, aging underwater structures, such as dam embankments at depths greater than 40m, which are challenging and dangerous for human divers [Sugimoto et al., 2017]. The system is designed to perform visual surveys, structural soundness evaluations (sounding, wall thickness), and navigate in deep and turbid water conditions [Sugimoto et al., 2017].

1 Design Choices and Architecture

1.1 Materials

This topic was not discussed in this design solution. The paper focuses on the inspection capabilities and system components rather than the specific materials used for the ROV's frame or pressure housings [Sugimoto et al., 2017].

1.2 Waterproofing and Chassis Design

The chassis is an open-frame design measuring 90cm in length, 56cm in width, and 63cm in height, with a weight of approximately 90kg [Sugimoto et al., 2017]. A key design feature is the main inspection unit mounted on the side of the robot, which includes extendable rods. These rods press against the dam body surface, allowing the inspection unit to remain parallel to the surface regardless of the dam's angle [Sugimoto et al., 2017]. Specific details on waterproofing methods were not discussed [Sugimoto et al., 2017].

1.3 Propeller Location and Prop Design Choice

The ROV is equipped with tri-directional thrusters that enable it to navigate freely in any direction and maintain neutral buoyancy [Sugimoto et al., 2017]. An automatic thruster control function allows the vehicle to hold its position at any desired depth and orientation [Sugimoto et al., 2017]. The paper does not specify the number, exact placement, or design of the thrusters [Sugimoto et al., 2017].

2 Hardware and Software

2.1 Chosen Propeller Motors and Other Sensors

The motor type for the thrusters is not specified [Sugimoto et al., 2017]. The ROV features a comprehensive sensor suite for inspection and navigation, including a high-resolution optical camera, a forward-mounted acoustic camera for turbid water, a 360-degree sonar system, a wall thickness gauge, and a sounding hammer with a hydrophone [Sugimoto et al., 2017]. A turbidity-reducing device can inject clear water to improve visibility [Sugimoto et al., 2017]. Positioning is achieved with a GNSS unit, direction sensor, water pressure gauge, and orientation/altitude sensors [Sugimoto et al., 2017]. LED lights provide illumination [Sugimoto et al., 2017].

2.2 Chosen Control Hardware

The system is operated from a station on a boat or land, which includes monitors for video and 3D positioning data, along with a handheld controller for maneuvering the ROV [Sugimoto et al., 2017]. The specific computing hardware or microcontrollers used on the ROV or at the operator station are not detailed [Sugimoto et al., 2017]. Operation is managed by an Operator and an Investigation Manager who uses the system's software to guide the inspection [Sugimoto et al., 2017].

2.3 Chosen Interfacing Architecture

The ROV connects to the operator station via an umbilical cable [Sugimoto et al., 2017]. The positioning system uniquely integrates a Global Navigation Satellite System (GNSS) on a buoy with an underwater acoustic positioning system (using a call and response method) to determine the ROV's location [Sugimoto et al., 2017]. All positioning data is combined with the ROV's internal sensor readings and displayed in real-time as a 3D model on the control screen for operator situational awareness [Sugimoto et al., 2017].

3 Control Systems and System Modeling

3.1 ROV Communication Method

Primary communication for data and control is handled through a physical umbilical cable [Sugimoto et al., 2017]. For positioning, the system uses an underwater acoustic communication link between a GNSS-equipped surface buoy and the ROV [Sugimoto et al., 2017].

3.2 Control Architecture

The ROV features both manual and automated control. An operator manually pilots the vehicle using a controller [Sugimoto et al., 2017]. The thruster system is equipped with an automatic control function to hold a specific depth and orientation, which is essential for stable and precise inspection tasks [Sugimoto et al., 2017].

3.3 System Modeling

This topic was not discussed in this design solution. The paper focuses on the system's architecture, components, and field verification results rather than mathematical modeling of the vehicle's dynamics [Sugimoto et al., 2017].

Design of Remotely Operated Vehicle Prototype for Ship Biofouling Inspection on Berth

Team: Sutan Azhary, Dedi Budi Purwanto, Hendro Nurhadi, et al. **Date:** August 14, 2025**Cite:** [Azhary et al., 2021]

Abstract

The purpose of this study was to design an ROV prototype capable of performing biofouling inspections on a ship's hull while it is berthed, eliminating the need for dry-docking [Azhary et al., 2021]. The key capability is the integration of machine learning, using an underwater image enhancement model (FUnIE-GAN) and an object detection model to effectively identify biofouling in real-time [Azhary et al., 2021].

1 Design Choices and Architecture

1.1 Materials

The vehicle's framework is constructed from **high-density polyethylene (HDPE) pipes**, which were chosen for being more water-resistant than PVC and non-toxic [Azhary et al., 2021]. An additional internal frame, which serves as a base for the pressure hull and a mount for thrusters, is made from an **acrylic sheet** processed using CNC cutting [Azhary et al., 2021].

1.2 Waterproofing and Chassis Design

The ROV is built with a central pressure hull unit that contains the electrical components and also serves as the center of buoyancy [Azhary et al., 2021]. This pressure hull is mounted on an external frame made of HDPE pipes. The overall dimensions are 42.9cm long, 18.7cm wide, and 11.7cm high [Azhary et al., 2021]. The design's stability was tested and adjusted using static ballast to achieve a suspended (neutrally buoyant) condition with minimal pitch and roll [**?**].

1.3 Propeller Location and Prop Design Choice

The ROV is equipped with four thrusters. Based on the system block diagram and design images, it appears to have two horizontal thrusters for forward/backward and turning maneuvers, and two vertical thrusters for controlling depth and pitch [Azhary et al., 2021]. The paper includes the formula for calculating propeller thrust based on fluid dynamics [Azhary et al., 2021].

2 Hardware and Software

2.1 Chosen Propeller Motors and Other Sensors

The specific motor type is not mentioned, but each of the four motors is connected to an Electronic Speed Control (ESC) unit [Azhary et al., 2021]. The sensor suite includes a camera for visual data collection and a **GY271 (HMC5883L) compass module** to provide stability and heading data [Azhary et al., 2021].

2.2 Chosen Control Hardware

An **Arduino UNO** microcontroller is used as the onboard unit for collecting stability data from the GY271 sensor [Azhary et al., 2021]. However, the primary processing for image enhancement and object detection is performed on a **laptop** at the surface, which receives the camera feed [Azhary et al., 2021]. A remote control is used for manual piloting [Azhary et al., 2021].

2.3 Chosen Interfacing Architecture

The system architecture splits the processing tasks. The Arduino UNO on the ROV handles low-level sensor data [Azhary et al., 2021]. The Human Machine Interface (HMI) consists of a remote control for piloting and a laptop for advanced processing [Azhary et al., 2021]. The remote control communicates with an onboard receiver, which sends signals to the ESCs to drive the motors [Azhary et al., 2021]. The camera sends its video feed to the laptop, where the image enhancement and object detection algorithms are executed [Azhary et al., 2021].

3 Control Systems and System Modeling

3.1 ROV Communication Method

The ROV uses two distinct communication methods. For manual piloting, a standard radio-frequency remote control communicates wirelessly with a receiver on the ROV [Azhary et al., 2021]. For the video feed and sensor data, a physical cable connection to the surface laptop is implied for real-time processing, although not explicitly detailed.

3.2 Control Architecture

The control architecture is primarily focused on the software for visual inspection. The system uses a two-stage machine learning pipeline. First, the raw underwater video feed is processed by a **Fast Underwater Image Enhancement model (FUnIE-GAN)** to improve clarity and color [Azhary et al., 2021]. Second, the enhanced image is fed into an **object detection model** (trained using Google AutoML) to identify and classify different types of biofouling [Azhary et al., 2021]. This process increased the ability to detect biofouling objects by an average of 155% [Azhary et al., 2021].

3.3 System Modeling

The paper provides a detailed model for image quality assessment, using equations for **Mean Square Error (MSE)**, **Peak Signal-to-Noise Ratio (PSNR)**, and **Structural Similarity Index Metrics (SSIM)** to quantitatively evaluate the performance of the image enhancement algorithm [Azhary et al., 2021]. It also includes the basic physics equation for calculating propeller thrust [Azhary et al., 2021]. No dynamic model of the vehicle itself is presented.

A low-cost 3D printed mini underwater vehicle: Design and Fabrication

Team: Marios Vasileiou, Nikolaos Manos, Ergina Kavallieratou **Date:** August 14, 2025**Cite:** [Vasileiou et al., 2021]

Abstract

The purpose of this ROV is to serve as a low-cost, modular, and customizable platform for inspection operations in shallow depths and confined environments, such as fish farm cages [Vasileiou et al., 2021]. The design prioritizes affordability (around 150 Euros), high maneuverability with five Degrees of Freedom (5-DOF), and ease of fabrication and modification through the use of 3D printing [Vasileiou et al., 2021].

1 Design Choices and Architecture

1.1 Materials

The hull and thruster mounts are 3D-printed using **PLA plastic filament** [Vasileiou et al., 2021]. This material was chosen because it is durable enough for water and moisture exposure, while supporting the project's primary goals of being inexpensive and easy to fabricate with rapid prototyping [Vasileiou et al., 2021]. The main body is comprised of six primary 3D-printed parts [Vasileiou et al., 2021].

1.2 Waterproofing and Chassis Design

The design is compact and modular, with dimensions of 376x300x87 mm and a weight of 1.5 kg [Vasileiou et al., 2021]. The chassis consists of 6 main 3D-printed parts, including a central cylinder for electronics and four integrated ballast tanks that act as fixed weights [Vasileiou et al., 2021]. The vehicle has marginally positive buoyancy, a key safety feature that allows it to surface automatically in case of a malfunction [Vasileiou et al., 2021]. The paper does not specify the methods used for waterproofing the electronic components within the hull [Vasileiou et al., 2021].

1.3 Propeller Location and Prop Design Choice

The ROV uses a six-thruster configuration to achieve five Degrees of Freedom (lacking only sway motion) [Vasileiou et al., 2021]. Four thrusters are oriented vertically in a square pattern to control heave, roll, and pitch movements [Vasileiou et al., 2021]. Two thrusters are oriented horizontally to control surge and yaw movements [Vasileiou et al., 2021]. Fins are attached to the horizontal motors to enhance stability and reduce unintentional roll [Vasileiou et al., 2021].

2 Hardware and Software

2.1 Chosen Propeller Motors and Other Sensors

The vehicle uses six small DC motors (800 RPM/V) chosen for being powerful yet quiet to avoid disturbing fish during inspections [Vasileiou et al., 2021]. The primary sensor is an **MPU6050 Inertial Measurement Unit (IMU)**, containing an accelerometer and gyroscope to determine orientation and velocity [Vasileiou et al., 2021]. A submersible camera provides visual feedback [Vasileiou et al., 2021].

2.2 Chosen Control Hardware

The central controller is a **Raspberry Pi 4 Model B**, selected for its affordability and versatile GPIO capabilities [Vasileiou et al., 2021]. The two horizontal motors are controlled by an **Adafruit DC motor shield** for variable speed, while the four vertical motors are controlled by eight relays for on/off actuation [Vasileiou et al., 2021]. The entire system is powered by a single 3-cell, 11.1V, 2700mAh Li-Poly battery [Vasileiou et al., 2021].

2.3 Chosen Interfacing Architecture

The ROV is operated via a physical tether connected to a surface device like a laptop or smartphone [Vasileiou et al., 2021]. A PS4 controller is used for manual piloting [Vasileiou et al., 2021]. Video is streamed up through the tether. The Raspberry Pi sends PWM signals to the Adafruit shield and relays to control the motors based on the operator's commands [Vasileiou et al., 2021].

3 Control Systems and System Modeling

3.1 ROV Communication Method

The ROV communicates with the surface station via a physical tether [Vasileiou et al., 2021]. The operator's PS4 controller connects to the surface device, which relays commands through the tether [Vasileiou et al., 2021]. The onboard IMU sensor communicates with the Raspberry Pi via the I2C bus [Vasileiou et al., 2021].

3.2 Control Architecture

The system is manually controlled by an operator using a PS4 controller [Vasileiou et al., 2021]. The Raspberry Pi 4 processes these inputs and sends corresponding PWM signals to the motor drivers [Vasileiou et al., 2021]. The IMU sensor data is used for orientation feedback, and the paper describes a calibration process that uses the sensor's onboard "Digital Motion Processor" to eliminate yaw drift and provide stable orientation data [Vasileiou et al., 2021].

3.3 System Modeling

The paper does not present a mathematical or dynamic model of the vehicle. However, it does provide a mobility analysis detailing how combinations of the six thrusters achieve the five degrees of freedom (surge, heave, roll, pitch, yaw) [Vasileiou et al., 2021]. Experimental results are shown to quantify the vehicle's rotational performance [Vasileiou et al., 2021].

Low-cost Remotely Operated Underwater Vehicle for Underwater Observation Purposes

Team: Wan Muhd Arif Bin Wan Sabri, et al. **Date:** August 14, 2025**Cite: [Sabri et al., 2017]**

Abstract

This paper details the development of a low-cost ROV designed for the observation of underwater environments. Key objectives were to create an agile system with precise navigation, an efficient live video feed, and a robust end-effector for object manipulation. The design also incorporates safety features like over-current and over-discharge protection, and a system to monitor battery voltage.

1 Design Choices and Architecture

1.1 Materials

To maintain a low cost, the ROV frame is constructed from **polyvinyl chloride (PVC) pipe** [Sabri et al., 2017]. This material was chosen for being lightweight and inexpensive [Sabri et al., 2017]. The gripper (end-effector) attached to the ROV is a custom component created using a **3D printer** [Sabri et al., 2017].

1.2 Waterproofing and Chassis Design

The chassis is a simple, open frame made of PVC pipes, with dimensions of 450x250x230 mm [Sabri et al., 2017]. The design forgoes complex enclosures; instead, waterproofing is achieved by manually sealing individual components (motors, camera, servo) with **silicon and petroleum jelly** [Sabri et al., 2017]. Buoyancy is managed by two adjustable, fixed ballasts (plastic bottles) where the internal air volume can be altered to achieve near-neutral buoyancy in different water types [Sabri et al., 2017].

1.3 Propeller Location and Prop Design Choice

The ROV uses a simple three-thruster configuration [Sabri et al., 2017]. Two thrusters are mounted horizontally at the rear to provide forward/backward motion (surge) and turning (yaw) [Sabri et al., 2017]. A single thruster is mounted vertically in the center to control the depth (heave) [Sabri et al., 2017]. This arrangement provides basic 3-DOF maneuverability and was chosen for its simplicity and low cost.

2 Hardware and Software

2.1 Chosen Propeller Motors and Other Sensors

The vehicle is propelled by three **12-volt DC motors**, driven by SmartDrive 40 motor drivers capable of handling up to 40 amperes [Sabri et al., 2017]. The sensor suite is minimal, consisting of a **reverse car camera** modified for waterproof operation to provide a live video feed, and a **potentiometer** configured as a voltage divider to measure the main battery voltage level [Sabri et al., 2017].

2.2 Chosen Control Hardware

Two **Arduino UNO** microcontrollers form the core of the control system [Sabri et al., 2017]. The first Arduino is dedicated to navigation, interpreting commands from the remote control [Sabri et al., 2017]. The second Arduino is used solely for monitoring the battery voltage via the potentiometer sensor [Sabri et al., 2017]. The entire system is powered by a lead-acid battery [Sabri et al., 2017]. All control electronics are housed in a surface control box, not on the ROV itself.

2.3 Chosen Interfacing Architecture

The system employs a surface-based control architecture. All main electronic components, including the two Arduinos, motor drivers, and power supply, are located in a control box at the base station [Sabri et al., 2017]. The ROV is connected to this box via a 15-meter, 10 AWG umbilical cable [Sabri et al., 2017]. A **PS2 controller** is used as the remote control, interfacing with the main Arduino via a PS2 shield [Sabri et al., 2017].

3 Control Systems and System Modeling

3.1 ROV Communication Method

All communication is handled through the physical umbilical cable. The Arduino at the base station reads commands from the PS2 controller and sends the corresponding power and control signals down the cable to the three DC thruster motors [Sabri et al., 2017]. The analog video signal from the camera is transmitted up the same cable to a monitor [Sabri et al., 2017].

3.2 Control Architecture

The control system is a direct manual, teleoperated architecture without any autonomous functions [Sabri et al., 2017]. The control algorithm on the main Arduino uses a simple polling method to continuously check for inputs from the PS2 controller [Sabri et al., 2017]. A ‘switch‘ statement in the code maps specific button presses directly to motor actions (e.g., forward, backward, turn, dive), including two-speed levels ("boost" mode) for each direction [Sabri et al., 2017].

3.3 System Modeling

This topic was not discussed in this design solution. The paper focuses entirely on the practical hardware implementation, component selection, and the direct control algorithm, with no mathematical or dynamic modeling of the vehicle.

Educational Small Scale Underwater Robot Development via a Capstone Project in Engineering Technology

Team: ORCA (Ocean Robotics Centered Applications) **Date:** August 14, 2025**Cite:** [Hur and Alvi, 2022]

Abstract

The purpose of this project was to develop a small-scale, educational Hybrid Remotely Operated Vehicle (HROV) through a student capstone project. This ROV was designed to be operated in either a tethered manual mode or a tether-less autonomous mode. Its primary functions are to conduct survey tasks and explorations in shallow channels, with the ability to autonomously perform a dive mission to measure water depth using a sonar sensor and record water temperature. The design was also intended to provide engineering students with practical experience and to participate in the MATE (Marine Advanced Technology Education) competition.

1 Design Choices and Architecture

1.1 Materials

The base frame of the underwater robot is constructed from aluminum extrusions. This material was chosen for the main structural component of the ROV.

1.2 Waterproofing and Chassis Design

The chassis is a frame constructed from aluminum extrusions with dimensions of $40\ cm \times 35\ cm \times 25$ cm. All the main electronics, including a custom interface PCB, are housed within a dedicated waterproof enclosure to protect them from the aquatic environment.

1.3 Propeller Location and Prop Design Choice

The ROV is equipped with a total of six thrusters. This configuration was chosen to allow the vehicle to navigate freely in the water. The specific layout or vectoring of the thrusters was not detailed in the paper, but images suggest a configuration for multi-directional movement. The design choice for the propellers themselves was not discussed.

2 Hardware and Software

2.1 Chosen Propeller Motors and Other Sensors

The propulsion system consists of six thrusters, each controlled by an Electronic Speed Controller (ESC). The specific model of the thrusters or motors was not specified. The sensor suite on the ROV is comprehensive and includes an Inertial Measurement Unit (IMU) for orientation, a Global Positioning System (GPS) for location when surfaced, a sonar sensor for measuring water depth, a pressure sensor, and a water temperature sensor. For visual feedback and navigation in dark environments, the vehicle is equipped with an underwater camera and two LED lights.

2.2 Chosen Control Hardware

The onboard control system is centered around a Raspberry Pi Zero W, which serves as the main controller unit. This is mounted on a custom-designed interface PCB. A 16-channel, 12-bit PWM/Servo Driver is used to manage the signals to the ESCs and any manipulators. The base station uses a Raspberry Pi 3 B+ for processing and communication, with an Xbox controller for manual piloting of the ROV.

2.3 Chosen Interfacing Architecture

A custom-designed 4-layer interface PCB is the core of the ROV's electronics. It mounts the Raspberry Pi Zero W, IMU, and GPS modules and provides connectors for all other sensors and actuators. The Raspberry Pi Zero W communicates with the sensors and the PWM driver via UART and I^2C buses. The PCB design incorporates an internal ground plane and a split power plane (3.3V and 5V) to reduce noise and ensure stable power distribution to the various components.

3 Control Systems and System Modeling

3.1 ROV Communication Method

The ROV is a hybrid system supporting two communication modes. For tethered operation, a detachable cable bundle connects the ROV to the base station; this tether includes lines for Ethernet, 12V power, and video. For tether-less operation, the ROV can receive commands from the base station via Wi-Fi (IEEE 802.11n wireless protocol) when it is at the surface.

3.2 Control Architecture

The control architecture supports both manual and autonomous operations. In manual mode, the operator uses an Xbox controller connected to the base station to pilot the ROV in real-time via the tether. In autonomous mode, the ROV can execute pre-programmed missions, such as scanning an area. It initiates these tasks after receiving commands wirelessly from the base station at the surface, then dives to collect sensor data at various depths, storing the data on an SD card for later retrieval.

3.3 System Modeling

This topic was not discussed in this design solution. The paper focuses on the physical design, system architecture, and the educational outcomes of the capstone project rather than the mathematical or dynamic modeling of the vehicle.

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