

DG-1 Technical Documentation



2026 Quadruple ROV Company:



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Abstract

This document covers the technical presentation of a Remotely Operated Vehicle (ROV), designated as DG-1, prepared by Team Quadruple representing Azerbaijan for the 2026 MATE ROV Ranger Class competition. The participation of a team from Azerbaijan in the MATE ROV competition for the first time is considered a significant milestone in terms of the development of underwater robotics and engineering fields in the country.

The developed ROV, DG-1, has been designed based on appropriate engineering principles to effectively perform the competition tasks and is equipped with efficient propulsion, monitoring, and control systems.

The preparation of the project has encompassed approximately one year of research and development. During this period, various practical tests were carried out to develop the conceptual design, integrate the systems, and verify the functionality of the vehicle.

The report presents the design concept of the ROV DG-1, the main engineering decisions and technical specifications, as well as the development stages that Team Quadruple went through in the process of creating a reliable and functional underwater robotic system.



Photo 1: QuadRuple Team

L→R : Nihad Ahmadli, Ali Ganizade, Javad Mammadli, Yunus Habibov, Omar Davudov

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Project Management

Company Structure - Quadruple is a company based in Azerbaijan, consisting of four members. The company was formed through the collaboration of school students who demonstrate a strong interest in underwater robotics and engineering, and who have distinguished themselves through participation in various underwater and technology-oriented competitions. All members are actively involved in every stage of the project and work in a coordinated manner across mechanical design, electronics, programming, and testing processes. This approach ensures agile decision-making, strong collaboration, and effective task distribution within the company. During each meeting, members come together to plan upcoming tasks, define objectives, and discuss technical solutions. Decisions are made through collective discussion, and each member contributes actively to the overall process. Within the company, an environment of mutual support, responsibility, and continuous learning has been established. Members enhance their knowledge across various technical domains, demonstrating a multidisciplinary approach. In addition, the company adheres to a safe working environment, operates in a structured and systematic manner, and focuses on achieving high-performance outcomes within limited timeframes. This approach enables the company to develop an innovative and competitive ROV system.

Scheduling and Planning - Quadruple Company conducts its project activities based on a structured and systematic approach. Within the company, planning, coordination, and continuous communication are adopted as the core principles to ensure the effective execution of tasks. Daily communication is maintained through messaging platforms and email, while remote collaboration is supported through online meetings organized via Zoom and Google Meet. This approach enables the company to maintain continuity and flexibility in its operations. For project planning and management, the Notion platform is utilized. Through this system, tasks are divided into stages, completed work is systematically recorded, and the overall process is continuously monitored. At the same time, areas requiring further development are identified and tracked accordingly. All technical documents, design files, and related materials are stored in a structured manner within Google Drive and shared internally. This increases data accessibility and contributes to a more efficient workflow organization (See Appendix A).

Thus, Quadruple Company effectively implements planning and task distribution through the use of digital tools and ensures the coordinated execution of its projects.

Design Rationale

The DG-1 ROV, developed by Quadruple Company, has been formed through the utilization of various technical resources during its design and manufacturing processes. The equipment available within the company, including 3D printing technologies, soldering tools, mechanical processing instruments, and laser cutting systems, enabled the construction of the DG-1 model and the production of its functional components. During the design phase, modern CAD and electronic design software were used to create precise component models,

and the operating principles of electronic systems were evaluated in advance. This approach allowed for design optimization and the early identification and elimination of potential technical issues. As a result, the DG-1 ROV is not based on standard off-the-shelf parts but is a unique system primarily composed of custom-designed and manufactured components. This design approach not only enhances the functionality of the device but also ensures compliance with the specified technical requirements. The details of this design are explained in the following sections.

Overall Vehicle Design & Systems Approach

The DG-1 Remotely Operated Vehicle (ROV) has been designed based on the principles of functional simplicity, reliability, and engineering optimization. The primary objective was to achieve maximum performance and stable operation with a minimal number of components. The DG-1 model was developed by the Quadruple engineering team using an iterative design approach. In the initial stage, mission tasks were analyzed, and various technical solutions were evaluated through sketches and conceptual models. The placement of components including thrusters, control module, camera, and manipulator was optimized with

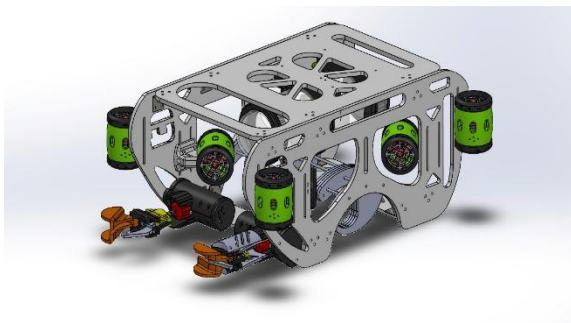


Figure 1: CAD Assembly

consideration of hydrodynamic balance and control precision. As a result of this process, a symmetrical thruster configuration was selected.

All structural components of the ROV were modeled from scratch using SolidWorks 3D CAD software (see Figure 1). The frame, propulsion system, and other key components were designed as an integrated and unified structure.

One of the key technical features of the DG-1 model is a custom-designed manipulator mechanism developed by the team. This system has been optimized both functionally and mechanically for interaction with underwater objects. In addition, the integrated camera system provides real-time visual monitoring and enables more precise control of the ROV. The DG-1 model represents an engineering solution that is hydrodynamically optimized, highly maneuverable, and capable of performing a wide range of underwater tasks.

Mechanical Design and Fabrication

The structural and propulsion architecture of the DG-1 ROV was developed based on the principles of hydrodynamic optimization, structural stability, and operational efficiency. During the redesign process, previous prototype limitations were carefully analyzed, and multiple engineering improvements were implemented to enhance underwater maneuverability, payload handling capability, and overall system reliability. The frame geometry of the DG-1 is based on a rectangular prism structure that provides balanced mass distribution, organized placement of internal components, and stable underwater operation. One of the major improvements introduced in the updated design was the reduction of the distance between the vertical lifting thrusters and the manipulator system. In previous tests, excessive separation between these components created additional torque during heavy payload handling, negatively affecting the stability of the vehicle. The updated configuration significantly improves load balancing and underwater stabilization during lifting operations. The side sections of the frame incorporate specially designed hydrodynamic cut-outs. These openings were optimized through multiple analyses rather than random placement. The primary objective was to achieve an optimal balance between drag reduction, structural strength, and efficient water circulation. The cut-outs allow water to pass freely through the structure, reducing hydrodynamic resistance, improving energy efficiency, and optimizing overall weight distribution. At the same time, these structural openings contribute to a more uniform stress distribution across the frame. To support heavy-object transportation tasks, two passive support arms were integrated near the center of gravity of the vehicle. This configuration allows lifting forces to remain centralized, significantly improving stability during underwater payload operations. The overall dimensions of the DG-1 platform are 65.5 cm in length, 34.5 cm in height, and 46.5 cm in width. These dimensions provide a compact yet highly stable structure capable of operating effectively in constrained underwater environments. Polyethylene (PE) was selected as the primary frame material due to its low density, high impact resistance, flexibility, and resistance to water and chemical exposure. These material properties reduce the overall weight of the system, simplify buoyancy adjustment, and increase durability under underwater operating conditions (see Figure 2).

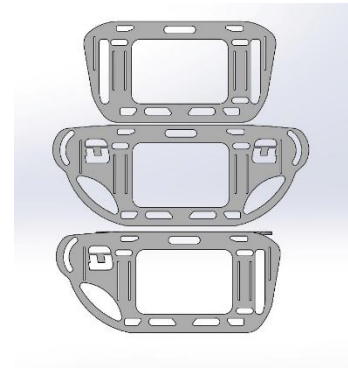


Figure 2: Frame Designs

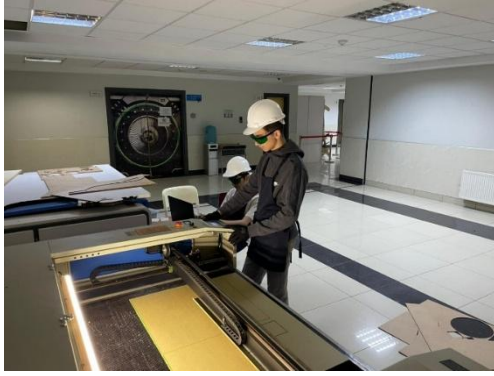


Photo 2: Work Proses

All structural components of the DG-1 were modeled from scratch using SolidWorks and manufactured using CNC laser cutting and advanced 3D printing technologies. During manufacturing procedures, all required technical safety protocols were strictly followed, and appropriate protective equipment was used while operating machinery and fabrication tools (see Photo 2). To evaluate the mechanical reliability of

the frame, structural stress analyses were conducted within the SolidWorks Simulation environment (see Figure 3). Various load conditions were applied during simulation testing, and the results demonstrated that the generated stresses remained within the allowable material limits. These results confirm that the DG-1 frame can operate reliably under real underwater working conditions without structural deformation. One of the key technical advantages of the DG-1 platform is its hybrid 8-thruster configuration. The propulsion system includes thrusters positioned both inside and outside the frame structure. This arrangement improves thrust distribution, increases maneuverability, and enables more efficient utilization of water flow while simultaneously protecting critical internal components. The DG-1 is additionally equipped with a four-camera vision architecture designed to maximize operator awareness and manipulator control efficiency. Two cameras are directly dedicated to manipulator observation and precision task execution. One forward-facing camera supports navigation and environmental monitoring, while an additional centrally positioned camera provides enhanced situational awareness around the vehicle. This multi-camera configuration significantly improves operational visibility, navigation precision, and overall mission control during complex underwater tasks.

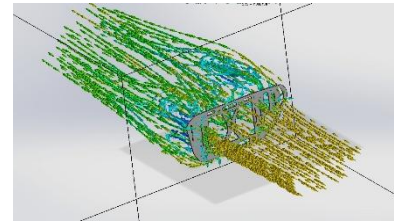


Figure 3: Frame Simulation

Propulsion



Figure 4: Thruster Layout

The propulsion system of the DG-1 ROV is based on ApigQueen U-01 thrusters, which are controlled via ApigQueen 45A continuous, bi-directional ESC modules. The system is powered by a 12V energy source and is limited by a 25A fuse for safety purposes. The eight thrusters used in the system operate with an approximate total current

consumption of 16A at maximum load, which represents an optimized solution in terms of energy efficiency. One of the key technical advantages of the DG-1 model is its 8-thruster configuration (see Figure 4). In this system, four thrusters provide movement and orientation along the X and Z axes, while the remaining four thrusters ensure stable vertical motion and



Photo 3: Thruster

depth control along the Y axis. Compared to conventional 6-thruster systems, the use of four thrusters along the Y axis enables more balanced stabilization and increased resistance to underwater currents. In addition, the placement of some thrusters at a 45° angle enhances the maneuverability of the DG-1 model. This configuration allows the vehicle to perform lateral movement along the Z axis (crab movement), enabling more precise maneuvering in confined and restricted spaces.

The thrusters used in the system are equipped with 400 KV brushless motors and four-blade propellers, providing high thrust and stable operational performance. Protective structures installed on the thrusters are designed in accordance with the IP22 standard. These protections prevent foreign objects and external particles from entering the propeller, ensuring both system safety and durability (see Photo 3). Compared to conventional 3D-printed protective structures, simulation and practical testing have shown that thick plastic guards restrict water flow and lead to performance loss. In the previous version, thin copper-wire motor guards were used to minimize hydrodynamic resistance. However, during operational testing, the copper wires deformed and changed shape due to their fragile structure. Therefore, the updated DG-1 model utilizes stronger plastic protective structures that provide improved durability while maintaining the required dimensions and operational safety.

Buoyancy & Ballast

The buoyancy and balance system of the DG-1 ROV has been developed based on the principles of structural design and optimized mass distribution. The primary objective is to maintain near-neutral buoyancy in underwater conditions and ensure stable operation in this state. Due to the use of lightweight materials in the structure (particularly the polyethylene frame) and the internal volume of the frame, initial evaluations indicated a positive buoyancy tendency in certain parts of the system. To regulate this balance, additional mass was placed in the lower section of the frame. This approach lowers the center of gravity, ensuring greater stability underwater and reducing the risk of tipping.

At the same time, the placement of components has been arranged in accordance with this principle. Heavier elements are positioned closer to the lower section, which contributes positively to overall stability.

The DG-1 model does not incorporate an active or variable buoyancy system (such as air-filled tubes or tanks). Instead, buoyancy is achieved entirely through a passive design approach via material selection, volume, and mass distribution. This approach preserves mechanical simplicity, reduces the likelihood of failure, and increases system reliability.

The buoyancy behavior of the ROV is based on Archimedes' principle:

$$F_B = \rho \cdot V \cdot g$$

where ρ is the density of water (approximately 1000 kg/m³), V is the displaced volume, and g is the gravitational acceleration. Considering the dimensions of the DG-1 model (0.655 m × 0.465 m × 0.345 m), the approximate maximum volume can be calculated as:

$$V \approx 0.655 \times 0.465 \times 0.345 \approx 0.105m^3$$

In this case, the maximum theoretical buoyant force is:

$$F_B = 1000 \times 0.105 \times 9.8 \approx 1029N$$

It is important to note that this value represents an ideal condition. In real scenarios, due to frame cut-outs, internal components, and water flow through the structure, the effective volume is lower. Therefore, the buoyancy of DG-1 has been practically optimized and adjusted to approach a neutral state. As a result, the buoyancy and balance system of DG-1 is based on a simple, reliable, and efficient approach, ensuring stable underwater performance without the use of additional mechanical systems.

Cameras

The DG-1 ROV utilizes a four-camera vision system designed for real-time navigation, environmental monitoring, and precise manipulator control (see Photo 4). During previous underwater operations, it was observed that the earlier dual-camera configuration created visibility limitations while simultaneously controlling manipulators and monitoring the surrounding environment. To overcome these challenges, the updated DG-1 platform was redesigned using four H.264-based cameras. Two cameras are directly dedicated to monitoring the manipulator systems, enabling more accurate object handling and task execution. The third camera is positioned in the front section of the vehicle for navigation and environmental observation, while the fourth camera is installed near the center of the platform to provide additional situational awareness



Photo 4: Camera

around the operational area. The positioning of the cameras was optimized considering the mechanical structure of the ROV, minimizing blind spots and improving operational visibility. The system supports high FPS Full HD (1080p) video transmission with low latency, enabling real-time monitoring and rapid decision-making during underwater missions. In addition, integrated auto-exposure and auto white balance functions improve image stability under varying underwater lighting conditions. As a result, the upgraded four-camera architecture significantly enhances navigation precision, manipulator control, and overall operational efficiency.

Underwater Measurement Method

In the DG-1 ROV, an image-based photo measurement (photometric measurement) method has been applied for object dimensioning. In this approach, the measurement process is carried out based on visual data obtained from the system, without the use of direct mechanical or physical measuring tools. The main principle of the method is based on capturing an image of the object without perspective distortion. For this purpose, the object to be measured is imaged by the ROV from a perpendicular view as much as possible. The acquired image is then analyzed using reference dimensions that are predefined within the competition framework, and other measurements are determined proportionally based on this reference. This approach can be applied in any 2D measurement environment, including CAD software or other graphical analysis tools. By establishing proportional relationships between dimensions on the image, real-world measurements can be calculated with high accuracy. To ensure effective system performance, the DG-1 model utilizes Razer Kiyo X cameras with high frame rates and high image quality. This enables the capture of clear and minimally distorted images, thereby improving measurement accuracy. The main advantage of the proposed method is that it allows the measurement of various objects solely based on visual data, without the need for additional mechanical or physical measuring devices. This makes the system both simpler and more operationally flexible.

Manipulator

The DG-1 ROV utilizes a dual-manipulator system positioned vertically to improve operational flexibility and enable the execution of multiple underwater tasks more efficiently (see Photo 5). During the development process, several engineering challenges were encountered, including waterproofing, motor selection, transmission reliability, and achieving sufficient gripping force for underwater operations. To overcome these limitations, a custom mechanical solution was developed using a brushless motor integrated with a gearbox system based on a worm gear mechanism. This configuration allows torque to be transferred only from the motor to the output shaft while preventing reverse transmission. As a result, the

manipulator can maintain its gripping position without additional energy consumption, providing stable and energy-efficient underwater operation.

The motion system was further integrated with a lead screw mechanism, creating a simple but highly reliable linear actuation system for opening and closing the manipulator jaws. The gripping structure consists of 3D-printed components and polyethylene gripper jaws, selected due to their flexibility, friction resistance, and durability in underwater environments(see Photo 6). During testing, structural failures were observed near the end sections of the manipulator under excessive load conditions. To solve this issue, a custom spring-based protection mechanism was integrated between the motor and the lead screw connection point. When the applied force exceeds a predefined threshold, the spring mechanism absorbs excess stress energy, preventing damage to the motor and the overall transmission system. Despite its relatively compact



Photo 5: Manipulator



Photo 6: Manipulator

mechanical structure, the manipulator system provides high gripping force, operational reliability, and modularity, enabling the DG-1 platform to perform a wide range of underwater manipulation tasks effectively.

Float

The “Nautilus” float system integrated into the DG-1 platform was developed to provide stable underwater positioning and reliable execution of mission tasks (see Photo 7). To achieve higher stability, the distance between the buoyancy chambers and ballast section was increased, significantly improving balance and reducing unwanted motion underwater. The buoyancy system operates using three 60 mL syringes controlled through a lead screw mechanism driven by a DC motor. A potentiometer integrated into the system allows precise control of the water volume entering the syringes, enabling accurate buoyancy adjustment during operation. The buoyancy calculations of the float system were analyzed based on Archimedes’ principle. Initial calculations showed that the float exceeded the neutral



Photo 7: “Nautilus” float

buoyancy limit by approximately 0.23 kg. Although additional ballast could fully compensate for this difference, the system was intentionally configured with slightly higher positive buoyancy to ensure that the float could return to the water surface after task completion. This configuration allows the syringe-based buoyancy engine to submerge and surface the float efficiently. The electronic control system utilizes NRF modules for wireless start communication, while an ESP32 microcontroller processes pressure sensor data to maintain the required underwater depth. The buoyancy control motor is additionally connected to a potentiometer, enabling precise monitoring and adjustment of water intake during operation. The system is powered using Li-ion battery technology, providing stable and efficient power delivery for long-duration underwater missions.

Tether

During previous underwater operations, several limitations were observed in the USB-based communication system previously used in the DG-1 platform. The USB cable demonstrated insufficient stability and bandwidth capacity when transmitting multiple high-resolution video streams simultaneously, particularly during complex underwater tasks. To overcome these limitations, the updated DG-1 communication architecture was redesigned using an optical fiber tether system. Compared to conventional USB communication, optical fiber provides significantly higher bandwidth, improved signal stability, and lower latency for real-time data transmission. The communication structure operates through the following sequence: surface computer → Ethernet connection → optical converter → optical fiber tether → internal converter → onboard communication system. This architecture enables stable transmission of high-volume visual and control data from the four-camera system with minimal signal degradation over long distances. The power supply system operates at 12 V with a maximum current limit of 25 A. To reduce energy losses while maintaining flexibility and maneuverability, 10 AWG power cables were utilized. System protection is ensured using a 25 A fuse positioned approximately 30 cm from the power source, protecting electronic components against overload and short-circuit conditions. In addition, Anderson connectors are used to provide reliable and fast power connection and disconnection during operation.

Software and Electronics

Command and Control

The mounting platform used for the placement of electronic components was manufactured using a 3D printer and was initially modeled in the SolidWorks environment (see Figure 5). During the design process, various structural alternatives were developed and evaluated in terms of mechanical compatibility, component arrangement, and cable management. As a result of iterative testing, the current design was identified as the most optimal solution, and the system was assembled based on this configuration. The electronic control system of the

DG-1 ROV is designed based on the principles of stable, safe, and efficient power distribution.

The system is powered by a 12V DC source, and upon entry, the power line is protected by a 25A fuse. This fuse interrupts the current in case of a short circuit or overload, preventing damage to electronic components (see Photo 8,9). After the fuse, the power line is directed to the main distribution point, from which it is distributed to different parts of the system. The 12V supply is directly delivered to ten 45A ESC modules. Eight of these ESCs are used for the thrusters, while the remaining two are allocated for the motors of the manipulator mechanisms. This approach ensures that both the propulsion system and the manipulators operate efficiently on the same power platform. At the same time, the power line is fed into

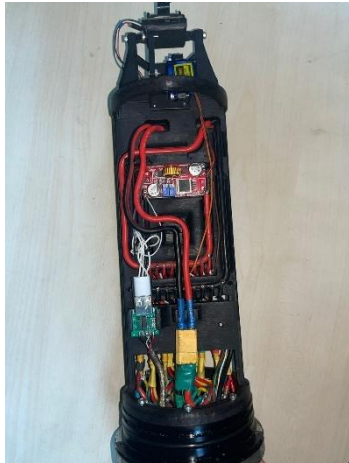


*Photo 9: Brain Electronics
Side 1*

an XL4016 voltage regulator, where the voltage is reduced from 12V to 5V. This lower voltage line safely powers components such as the USB hub, Arduino Nano, and servo motor. The main control unit of the system is the Pixhawk 2.4.8 flight controller. This controller maintains the stability of the ROV and processes all motion commands, transmitting them to the ESC modules via PWM signals. The ESCs then convert these signals into high-power outputs to drive the respective motors.



*Photo 8: Brain Electronics
Side 2*

For additional control functions, an Arduino Nano is integrated into the system. The Arduino controls a servo motor to adjust the camera's viewing angle, allowing more flexible visual monitoring during operation. All data transmission lines within the ROV are connected through a USB hub. Data from the cameras, Pixhawk, and Arduino are collected through this hub and transmitted via a single output line through the tether cable to a surface computer. This system enables real-time transmission of video and control signals with low latency.

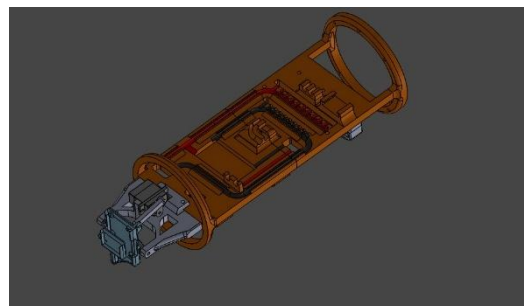
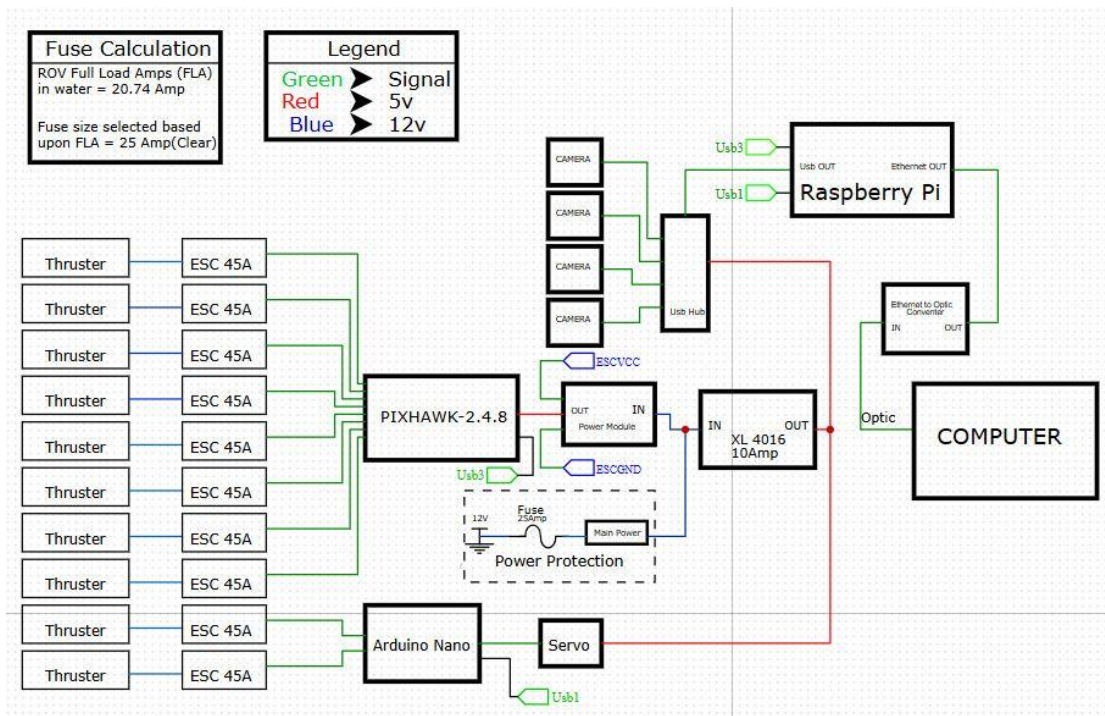


Figure 5: Platform

Systems Integration Diagram (SID) for ROV

System Integration Diagram (SID), ROV:

Legend: Red=5v, Blue=12v, Green=Signal



Control Systems Design

The control system of the DG-1 ROV is an integrated software and electronics architecture designed based on the principles of real-time reception, processing, and execution of user commands. The system is developed to ensure continuous and low-latency communication between the surface control station and the onboard actuation mechanisms of the ROV.

The control application is developed using the Python programming language and serves as the main interface between the user and the system. This application receives user commands and processes feedback data (visual and control signals) returned from the ROV, presenting it to the operator. Thus, the system operates based on a bidirectional communication principle.

This architecture is based on the principles of simplicity and reliability, enabling direct and efficient control without the use of complex network protocols. This approach is particularly advantageous in real-time systems, where minimizing latency is critical.

Main Command Module

In the DG-1 system, user input processing is implemented using the Pygame library. This library reads analog and digital signals from the Xbox controller in real time and converts

them into structured control commands. These commands are used to operate the manipulator systems, servo mechanisms, and other controlled components. For transmitting control signals to the physical system, an Arduino Nano microcontroller is utilized. Communication between the Arduino Nano and the surface computer is established via the PySerial library. This library ensures stable and continuous serial communication over the USB interface, enabling commands sent from the Python application to be received by the microcontroller. The Arduino Nano processes incoming serial data and converts it into appropriate control signals (PWM or digital signals), which are then transmitted to the corresponding actuating mechanisms. This approach ensures a modular system structure and creates a clear interface between the software and the physical system.

Within the Arduino environment, the Servo library is used for controlling both servo motors and ESC modules. This library enables precise and stable generation of PWM signals, simplifying the control of both servos and ESCs. Through this library, speed control signals are transmitted to the ESCs, while servo mechanisms are controlled at specific angle values. The division of the system in this manner (high-level control – Python, low-level control – Arduino) ensures more stable and scalable control architecture.

Vision & OpenCV Module

In the DG-1 ROV, the OpenCV library is utilized for the acquisition and processing of visual data. Images obtained from the onboard cameras are captured in real time via OpenCV and transmitted to the operator interface. The OpenCV library provides efficient and fast mechanisms for image acquisition, display, and management. Through this system, the operator can switch between different camera sources, activate or deactivate the video stream, and observe the operational environment from multiple perspectives.

Operating with high FPS and low latency, this module forms the foundation of the DG-1's visual monitoring system and supports precise decision-making during manipulator operations. The real-time transmission of visual data is particularly critical in underwater environments where visibility is limited.

System Workflow

The DG-1 control system operates based on a sequential and integrated process. Commands provided by the user via the Xbox controller are first read in real time using the Pygame library. These signals are then processed by the Python application and converted into corresponding control commands. The generated commands are transmitted to the Arduino Nano microcontroller via the PySerial library. The Arduino receives this data, converts it into physical actuation signals, and activates the corresponding motors and servo mechanisms.

In parallel, images captured by the cameras are transmitted to the operator in real time through the OpenCV library, ensuring the system's visual monitoring capabilities.

Build vs. Buy, New vs. Reused

During component selection for the DG-1 model, primarily new materials were utilized; however, certain components and experience obtained from previous underwater competition projects were also taken into consideration. This approach ensured the continuity of technical knowledge and enabled the integration of insights gained from earlier systems into the new design. The majority of the components used in the manufacturing process were produced from scratch, with filament materials serving as the primary resource. In particular, complex and customized components were manufactured using the FlashForge Adventurer 5M Pro 3D printer. This technology played a significant role in ensuring mechanical compatibility and supporting a modular construction approach. For components requiring higher dimensional accuracy and structural rigidity, the Snapmaker A250 CNC system was employed. This system enabled precise material processing and ensured dimensional stability. Additionally, the CO2 LESTAR 1390W4-DH laser cutting system was used for the production of flat and structural elements. With its high power and large working area, this system allows fast and precise material cutting while maintaining accuracy and repeatability throughout the manufacturing process. Overall, the manufacturing approach applied in the DG-1 model is based on an optimal combination of newly developed components and previously acquired experience, positively contributing to both performance enhancement and production efficiency.

Testing and Troubleshooting

During the development of the DG-1 ROV, the testing and troubleshooting process was carried out in a staged manner to ensure reliable system performance. Whenever a fault was detected, the source of the problem was identified, possible solutions were evaluated, and the most appropriate approach was implemented. Mechanical and electronic components were first tested individually and then in an integrated configuration.

During the software phase, the transmission of control signals and system response were verified, and based on the results, the control algorithms were optimized. During the assembly of electronic systems, all connections were checked for short circuits and contact stability, and circuit continuity was tested using a multimeter. After full system assembly, initial dry tests were conducted, followed by functional tests in an underwater environment. In cases of malfunction, power supply, signal transmission, and component operation were systematically analyzed, and once the issue was resolved, the system was re-tested. As a result of this iterative approach, stable and reliable operation of the DG-1 was ensured.

Safety

During the development and operation of the DG-1 ROV, the safety of team members was considered a primary priority. Considering the technical complexity of the project and the potential risks associated with the equipment used, all members were initially familiarized with safety procedures, and strict adherence to these rules was maintained throughout the process. Activities within the organization were conducted in a controlled and coordinated

manner, minimizing risks during equipment usage. During the manufacturing and assembly phases, appropriate safety measures were implemented while working with CNC, laser cutting, and 3D printing equipment. Personal protective equipment was used, and the working environment was kept under supervision. During the assembly of electronic systems, special attention was given to checking short circuits, insulation, and connection stability.

Technical safety measures were also incorporated into the ROV design. The thrusters were equipped with protective elements, sharp edges were eliminated from external parts, and suitable design approaches were applied to ensure the safe operation of mechanical systems. The manipulator mechanisms were designed to minimize the risk of compression during use. Electronic components were placed inside insulated enclosures to prevent contact with water, and the power supply line was protected by a 25A fuse. This approach ensures both system safety and durability.

During underwater testing and operations, particular attention was paid to safety protocols around the pool area. Running near the pool was prohibited to prevent slipping hazards, electrical cables were kept away from water contact, and all power connections were continuously monitored. The ROV was operated only after all safety checks had been completed.

Operational Checklists and Protocol

To ensure the safe and efficient operation of the DG-1 ROV, operational procedures are carried out based on predefined checklists and protocols. This approach enables all stages from system preparation to operation and post-operation to be executed in a sequential and controlled manner. Operations related to the tether system are performed according to a specific protocol. Before use, the tether is uncoiled, all twists are removed, and the cable is securely connected to the control unit. To prevent disconnection due to tension, strain relief mechanisms are secured both to the control unit and the ROV. Team members are also instructed in advance to avoid stepping on the tether. After the operation is completed, the tether is safely disconnected and properly coiled for storage. The surface control phase is conducted in a defined sequence. First, the tether protocol is executed, and the system is powered on, bringing it to a 12V operating level. The ROV is then activated, and the thrusters, manipulator systems, and camera feed are tested via the control interface. Once all systems are confirmed to be functioning correctly, the ROV is carefully deployed into the water, trapped air bubbles are released, and operational readiness is confirmed among team members before initiating the mission. Pre-operation checks are aimed at evaluating the technical condition of the system. At this stage, electrical connections are verified, dry tests are conducted to confirm the functionality of the camera and propulsion systems, the sealing integrity of waterproof enclosures is inspected, and both the free operation of thrusters and the functionality of manipulator mechanisms are tested. After the completion of operations, the system is safely deactivated. Power is turned off at the control unit, and the power source is disconnected. The tether protocol is then applied, the cable is detached and neatly stored. The ROV is dried and placed into a safe storage condition, and the workspace is cleared of

used tools and materials. These operational procedures ensure safety, consistency, and efficiency during the use of the DG-1 ROV.

Budget and Cost Accounting

Budget

During the development of the DG-1 ROV project, initial budget planning was carried out to ensure structured and efficient cost management. The total project expenditure amounted to 3751.67 USD. This budget was determined by considering the materials used, electronic components, manufacturing processes, and other technical requirements.

Funding

The development of the DG-1 ROV was funded by STEAM Azerbaijan, a project of the Ministry of Science and Education of the Republic of Azerbaijan. This support served as the primary financial source for project development, acquisition of technical equipment, and execution of the manufacturing process.

Spending

Cost management within the project was implemented through a systematic approach. Required components were researched in advance, evaluated in terms of technical compatibility and functionality, and only essential parts were prioritized for procurement. During the manufacturing process, preference was given to locally produced components where possible, as well as to the use of 3D printing, CNC, and laser cutting technologies.

This approach enabled both the optimization of financial resources and the development of a more flexible and customized technical solution. As a result, the DG-1 model was developed as a functional, reliable, and high-performance system within the available budget.

Item	Qty	Unit Value (\$)	Total (\$)
apisqueen u01 underwater thruster	13	25.73	334.49
cyclone 45a esc	12	27.39	328.68
xbox wireless controller	1	63	63
Pixhawk 2.4.8	2	160	320
LM2596	3	10	30
XL4015 5A DC to DC	3	19.61	58.83
DC 5V 10A Relay Module	2	1.75	3.5
DC 12V 80A Relay Module	2	2.8	5.6
ky025 reed switch	2	5.91	11.82
Arduino Nano	5	25	125
Copper Plate	2	5.32	10.64
XT60 Connector	4	3	12

MR30 Connector	1	17	17
Pixhawk Power Module	2	14.89	29.78
Wire Kit	1	26	26
Heat Shrink Tube Set	2	17.33	34.66
DC Gear Motor	4	14.35	57.4
Razer Kiyo X Camera	3	63.04	189.12
Silicon Cable	5	2.85	14.25
Extension Cable	3	9.53	28.59
PLA Filament	9	14	126
Solder	1	13	13
Solder Pump	2	10	20
USB Hub	2	4	8
Desoldering Wick	1	10	10
Epoxy Resin Kit	1	19	19
Soldering Kit	2	10	10
Acrylic Dome Lens	1	51.05	51.05
XL4016 10A DC	2	51.05	102.1
Polyethylene Sheet	1	38.24	38.24
Watertight Enclosure	2	34.90	69.8
Water Tight Enclosure	2	84.71	169.42
Zip Ties Pack	1	26.32	26.32
Drill Driver Kit	2	75	150
Wire Cutter	4	2	8
Multimeter	1	32.93	32.93
Servo Motor	2	2.45	4.9
YS Penetrator	20	14.26	285.2
Steel Pliers	2	21	42
Hex Keys	2	26.02	52.04
Screwdrivers Set	2	43.83	87.66
Plexiglass	1	75	75
Rasperry pi 4B -4Gb	1	55	55
Fiber optic to ethernet converter	1	40	40
Fiber optic cable 50m	1	30	30
H265 cameras	4	60	240
		Total	3554.59 \$

Item	Qty	Unit Value (\$)	Total (\$)
4 way pipe connector	54	0.21	0.94
Elbow pipe fitting	70	0.15	8.1
Pipe cap	20	0.18	3.6

3 way pipe connector	2	0.47	14.7
Pipe 3.5 Meter	11	6.18	67.98
PLA Filament	1	14	14
Screw and Nut Set	1	12.66	12.66
Plexiglass	1	75	75
		Total	196.98 \$

Table 1: Costing Summary For QuadRuple (vehicle and control systems)

Table2: Costing Summary Testing supplies

Expense Category	Cost Per Person (USD)	Total for 8 People (USD)
Round-Trip Flight Tickets	1550	12400
Hotel / Accommodation	420	3360
Food & Daily Meals	240	1920
Local Transportation	90	720
Canadian Visa Fee	185	1480
Travel Insurance	45	360
Extra / Emergency Expenses	150	1200
Total	2680\$	21440 \$

Table3: Estimated Budget Plan

References

1. BlueROV2 Underwater Robot (Search Reference) - <https://www.bing.com/search?q=bluerov2+underwater+robot>
2. Deringezen Pro ROV (DEGZ Robotics) - <https://degzrobotics.com/product/remotely-operated-vehicle-rov-deringezen-pro/>
3. Blue Robotics BlueBoat Software Setup - <https://bluerobotics.com/learn/blueboat-software-setup/>
4. OpenCV Multiple Image Display (Toolify Article) - <https://www.toolify.ai/ai-news/opencv-display-multiple-images-in-one-window-python-3378343>
5. Underwater ROV Community (UWROV) - <https://uwrov.org/>
6. OpenCV Official Website - <https://opencv.org/>
7. Pygame Documentation - <https://www.pygame.org/docs/>
8. Pixhawk Official Website - <https://pixhawk.org/>
9. BLHeliSuite ESC Software (GitHub Releases) - <https://github.com/4712/BLHeliSuite/releases>
10. PySerial Python Library - <https://pypi.org/project/pyserial/>
11. Arduino Servo Library (GitHub) - <https://github.com/arduino-libraries/Servo>
12. BlueROV2 Underwater Robot (Search Reference) - <https://www.bing.com/search?q=bluerov2+underwater+robot>
13. PiCam360 ROV Project - https://www.picam360.com/projects/picam360_rov
14. ROV Maker Platform - <https://rovmaker.com/en/>

Appendix

Task Description	Responsible	Status	Technical / Operational Notes
Concept development and initial ROV design planning	Team	Done	General system concept and mission requirements defined
CAD modeling of ROV frame structure	Javad Mammadli	Done	Structural stability ensured, weight optimized
Mechanical assembly of frame components	Javad Mammadli	Done	Assembly completed, minor alignment adjustments applied
Waterproof sealing and insulation of ROV enclosure	Javad Mammadli	In Progress	Minor leakage detected, additional sealing applied
Thruster (motor + propeller) installation	Omar Davudov	Done	All motors functional, rotation direction calibrated
Electrical wiring and circuit integration	Omar Davudov	In Progress	Cable management needs optimization
Power distribution system setup (battery + ESC)	Omar Davudov	Needs Fix	Voltage fluctuation observed under load
Camera system and live video transmission setup	Ali Ganizade	Done	Stable video feed achieved
Control system (receiver + transmitter) configuration	Ali Ganizade	In Progress	Slight signal delay detected
Software development and control logic programming	Ali Ganizade	Needs Fix	Code requires optimization for smoother control
Pilot training and maneuverability testing	Yunus Habibov	In Progress	Control precision improving with practice
Underwater stability and balance testing	Yunus Habibov	Needs Fix	Stability issues detected during movement
Preparation of test field elements for competition simulation	Yunus Habibov	Done	Test obstacles and environment successfully prepared
Internal system integration and full system testing	Team	In Progress	Subsystems integration ongoing
Troubleshooting and performance optimization	Nihad Ahmedli	In Progress	Multiple minor issues under review
Budget planning and financial resource allocation	Omar Davudov	Done	Budget structured and approved
Procurement and materials management	Omar Davudov	In Progress	Some components delayed
Documentation of engineering process and reporting	Nihad Ahmedli	In Progress	Technical documentation being finalized
Preparation of presentation materials and project explanation	Team	In Progress	Slides and explanations under development

A: Project Schedule

Job Safety Analysis (JSA)

Section	Task	Hazard Description	Safety Protocol
Pool Entry/Exit	Carrying ROV	Heavy lifting injury	Lift with partner, use knees, communicate
Pool Entry/Exit	Carrying ROV	Finger injury	Use handholds, keep hands safe
Pool Entry/Exit	Movement	Tripping	Walk carefully, watch tether
System Setup	Control deck setup	Water damage	Keep control deck away from pool
System Setup	Tether setup	Tripping	Inform team, manage cable

Power Checks	Pre-run check	Water exposure	Check waterproofing
Power Checks	System check	Electrical shock	Check connections and seals
Pool Operations	ROV operation	Injury	Wear closed shoes
Pool Operations	Claw use	Hand injury	Alert pilot, keep distance
System Breakdown	Disconnect power	Electrical shock	Turn off power first
System Breakdown	Cleaning area	Tripping	Remove all objects

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