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1 Abstract

Designed to confront the challenges of climate change in the Great Lakes and Oceans, Kamikaze is E-JUST Robotic Club's entry for the 2025 MATE ROV Competition. Constructed for the purposes of ocean monitoring, marine renewable energy, and ecosystem restoration, it promotes the UN Decade of Ocean Science and propels sustainable developments in underwater exploration. Kamikaze is a product of 47 employees to deliver a robust and mission-ready solution. With only three years of experience, Kamikaze was a large step up from its predecessor Shiro Kaigen, where modularity, sustainability, adaptability and ease of pilot were the main design choices while designing. Kamikaze improves on its predecessor but using a modular aluminum extrusion frame allowing the ease of modification and the specialized tools that can accomplish more specific tasks. Kamikaze also implements a new manipulators design made to grip on a wide range of sizes, a lightweight 3D-printed PETG canister, a seven-thruster propulsion system with six degrees of freedom. In addition to that, Kamikaze also implements new custom-made PCB with STM32 microcontroller, a custom depth sensor, the usage of aluminum wires and built up from ground software with a new custom station to control it.

Kamikaze is prepared to perform jobs ranging from documenting Great Lakes shipwrecks to collecting water samples, deploying hydrophones, and maintaining offshore wind farm bases. Accompanied by a custom-built vertical profiling float for autonomous data collecting on ocean health and depth, it becomes a realistic solution for the preservation of great lakes and oceans.

Figure 1: E-JUST Robotics Club Team.

2 Design Rationale

2.1 Design Evolution

The development of **Kamikaze** was the result of a step-by-step design process that began with a critical evaluation of last year's model, Shiro Kaijin (Figure 2). By identifying its limitations, we carefully assessed alternative solutions, ensuring that each design decision balanced performance, cost, and operational efficiency.

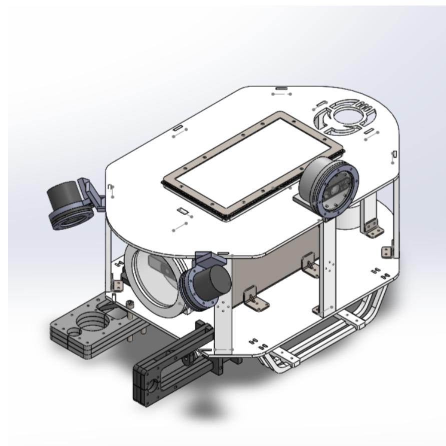


Figure 2: Last year's ROV - Shiro Kaijin.

Our team conducted structured brainstorming sessions to explore innovations that would enhance functionality while maintaining cost-effectiveness. Through a holistic systems approach, we ensured seamless integration between mechanical, electrical, and software components, optimizing overall performance. As a result, Kamikaze (Figure 3) represents a well-planned evolution that enhances reliability, efficiency, and mission adaptability.

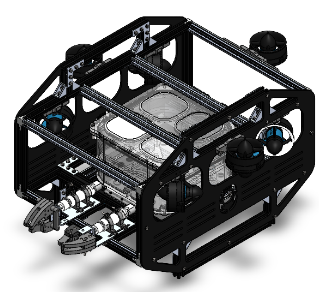


Figure 3: Kamikaze.

2.1.1 Mechanical System Evolution

Frame and Structural Improvements
Shiro Kaijin's frame was constructed entirely from HDPE, which posed challenges in component fixation. Drilling holes for mounting often led to overlap issues, making modifications difficult. To address this, Kamikaze features a modular aluminum extrusion body, enabling flexible component placement, quick adjustments, and easier repairs.

Canister Evolution
One of the major design advancements in Kamikaze is the transition from an aluminum canister to a 3D-printed PETG canister. While aluminum provided durability, it was costly, difficult to modify, and unnecessarily heavy. The new 3D-printed PETG canister offers greater design flexibility, allowing for customized internal layouts, easy adjustments, and rapid prototyping without the constraints of metal fabrication.

Propulsion System
Kamikaze improves upon its predecessor's six-thruster configuration by adopting a seven-thruster setup, enhancing maneuverability and control. However, in line with cost-efficiency objectives, all thrusters from last year's model were reused, maintaining a balance between improved functionality and resource optimization.

Gripper Mechanism Enhancement
Shiro Kaijin's gripper was limited to fixed circular openings, restricting it to predefined object sizes. Kamikaze introduces a versatile gripping mechanism capable of adapting to various object dimensions, significantly increasing efficiency and flexibility in underwater tasks.

Improved Piloting and Camera System
Kamikaze enhances operational efficiency with an upgraded camera system supporting multiple camera types with rotation and tilt functionality. This ensures a comprehensive, adaptable view of the environment, improving pilot control and situational awareness.

2.1.2 Electrical System Evolution

Power Connection and Cable Management Issues
Shiro Kaijin faced instability in power connections due to disorganized cables, causing electrical noise and intermittent connectivity. Each ESC was connected separately, leading to excessive wiring and limited space within the canister. To resolve this, Kamikaze integrates all ESCs into a single PCB, significantly reducing cable clutter, minimizing electrical noise, and improving system stability. Additionally, an STM32 microcontroller was added to the power PCB, further optimizing wiring and ensuring a more reliable electrical system.

Inadequacy of Arduino UNO
The Arduino UNO, used as the main controller, struggled to handle multiple sensors, leading to irregular data handling and performance issues. Kamikaze replaces it with an STM32 microcontroller, offering better stability, higher processing power, and improved efficiency for industrial applications.

CAN Bus Integration
To further enhance system communication, a CAN bus was integrated, enabling reliable data exchange between multiple STM32s, reducing wiring complexity, and allowing independent node resets without affecting the overall system. This implementation ensures robust and efficient communication, critical for the seamless operation of Kamikaze's various subsystems.

Limitations of MS5540 Depth Sensor
The MS5540 depth sensor was inaccurate, slow, and costly, making it an inefficient choice. Kamikaze replaces it with a custom-designed depth sensor, providing real-time, accurate measurements and better connectivity options. To improve monitoring capabilities, voltage and current sensors were also implemented, allowing precise tracking of power consumption and early detection of system faults.

Reliability of Main Control PCB
Shiro Kaijin used relays in the main control PCB, which affected system stability. Kamikaze replaces them with MOSFETs, enhancing reliability and improving over-

all performance. Additionally, a debugging node using the W5500 Ethernet module was introduced, enabling real-time system monitoring and remote reset of multiple nodes, ensuring continuous stability and efficient troubleshooting.

Switching from Copper to Aluminum Wires
Copper wires in high-power transmission corroded quickly, posing safety risks. Kamikaze replaces them with aluminum wires, which are lighter, more durable, and resistant to redox reactions, ensuring safer and more efficient power transmission.

2.1.3 Software System Evolution

ZED Camera
This year, we added a stereo camera to our ROV to enhance our navigation capabilities. The ZED2i camera is capable of providing depth perception and 3D mapping, which can be utilized in Task 1: Shipwreck length estimation. We exploited epipolar geometry algorithms to be able to estimate the length of the ship from the depth data provided. We believe that this addition is crucial to the development of our ROV, and it's a decent investment for the future.

μROS
We improved our communication model even more by the integration of micro-ROS, a ROS 2 implementation for microcontrollers, on one of the STM32 we have. We used micro-ROS Ethernet to connect the STM32 to the top-side computer, which is running ROS 2, allowing for seamless integration between the microcontrollers and the main computer. Micro-ROS ensures real-time communication and efficient data exchange, enhancing the overall performance of our ROV.

2.2 Design and Manufacturing Process

2.2.1 Conceptual Design

The design process began with a comprehensive evaluation of last year's ROV to identify areas for improvement. The team focused on two primary aspects: performance optimization and the integration of new features required for this year's tasks.

To ensure a structured approach, brainstorming meetings were conducted to analyze feasibility, cost, and impact on overall performance. One of the major innovations was the adoption of a modular aluminum extrusion body, a strategic decision aimed at enhancing adaptability and extending the ROV's lifespan.

Another key challenge was selecting suitable material for the electronic canister. An aluminum design was initially considered but was found to be twice as expensive as a 3D-printed alternative. After evaluating material strength and pressure resistance, the team decided to proceed with 3D printing, ensuring a cost-effective and flexible solution that could withstand underwater conditions while being easy to assemble and modify.

2.2.2 Preliminary Design

Once the core design concepts were defined, SolidWorks simulations were conducted to evaluate structural integrity, hydrodynamics, and thruster configurations. These data-driven insights played a critical role in optimizing component placement and material selection.

To ensure an optimal balance between performance and affordability, a trade-off matrix (Figure 4) was developed, comparing materials based on weight, cost, and manufacturability. Additionally, build vs. buy decisions were assessed, ensuring that in-house manufacturing was pursued where it provided a functional and economic advantage, while outsourcing was considered for components requiring specialized fabrication.

[redacted]

Figure 4: Material Selection

To validate these theoretical analyses, small-scale prototypes were developed for key components. The

3D-printed canister was tested for sealing effectiveness, and successful trials confirmed its reliability before moving to full-scale manufacturing. Camera housings were also prototyped to optimize field-of-view placement. This iterative process allowed for practical verification of design choices before finalizing the ROV.

2.2.3 Detailed Design and Manufacturing

With validated designs, the final ROV model (Figure 5) was fully developed in SolidWorks, incorporating stress, buoyancy, and flow simulations to ensure structural stability and hydrodynamic efficiency.

[redacted]

Figure 5: Kamikaze Drawings

For manufacturing, a systems-based approach was taken:

- The aluminum plates body was Laser CNC-machined and assembled using precise modular connectors.
- The canister was made using 3D printing, with design improvements tested through simulation and prototype experiments.
- The grippers and other HDPE parts were cut using router cutters, leveraging precise CAD models to minimize material waste. 2D CAD models (Figure 6) were generated to optimize material usage.

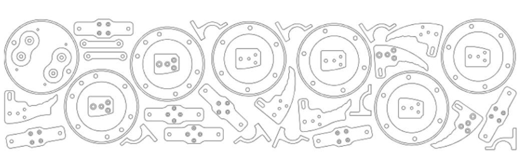


Figure 6: DXF file for cutting the float and grippers.

For the electrical system, significant innovations were implemented:

- The ESCs were integrated into a single PCB, reducing wiring complexity, electrical noise, and space consumption within the canister. This improvement streamlined system integration and enhanced overall performance. (Figure 7)
- A custom-designed depth sensor replaced the previous board, offering higher accuracy, real-time measurements, and expanded connectivity options. This upgrade ensured more precise and reliable depth control.

[redacted]

Figure 7: PCB

Finally, the complete ROV assembly was tested to ensure seamless integration of mechanical, electrical, and software components.

2.3 Vehicle Core Systems

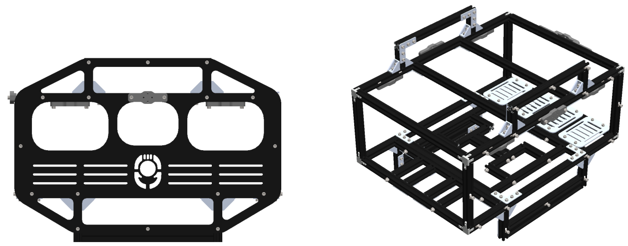
2.3.1 Mechanical System

2.3.1.1 Frame

Kamikaze's frame (Figure 8b) is designed using a cuboid aluminum V-extrusion structure, providing a stable and modular foundation for mounting various components. The 20×20 and 20×40 aluminum extrusions offer a strong yet lightweight framework that maintains structural integrity in underwater conditions.

To enhance stability and buoyancy, HDPE side frame sheets (Figure 8a) are integrated into the design. These sheets not only contribute to the aesthetic appeal of the ROV but also help in maintaining balance during operations. Their strategic placement ensures that the ROV remains hydrodynamically stable while supporting the overall structural framework.

The frame is designed with precise mounting slots, allowing secure positioning of thrusters, cameras, and



(a) HDPE Side Frame. (b) Aluminum Extrusion Frame.

Figure 8: Kamikaze's Frame Illustration.

operational tools while maintaining easy access for maintenance. The bolted assembly ensures that components can be reconfigured or replaced without permanent modifications.

Additionally, the frame is tailored for the E-JUST Robotics team, ensuring compatibility with the mission requirements of the MATE ROV competition while balancing durability, weight efficiency, and adaptability.

2.3.1.2 Propulsion

Kamikaze is equipped with seven T200 Blue Robotics thrusters, strategically placed to achieve six degrees of freedom for precise maneuverability (Figure 9). This setup balances performance, power consumption, and cost-efficiency, ensuring mission success without excessive energy use.

Using seven thrusters instead of a larger number reduces power draw while maintaining stability and control. Each thruster's power consumption is affected by drag force, given by:

$$F_d = \frac{1}{2} C_d \rho A v^2 \tag{1}$$

Where:

- F_d = Drag force (N)
- C_d = Drag coefficient (ROV shape-dependent)
- ρ = Water density (kg/m^3)
- A = Cross-sectional area (m^2)
- v = ROV velocity (m/s)

A CFD flow simulation was conducted to analyze water flow around Kamikaze (Figure 10), minimizing drag and enhancing hydrodynamic efficiency.

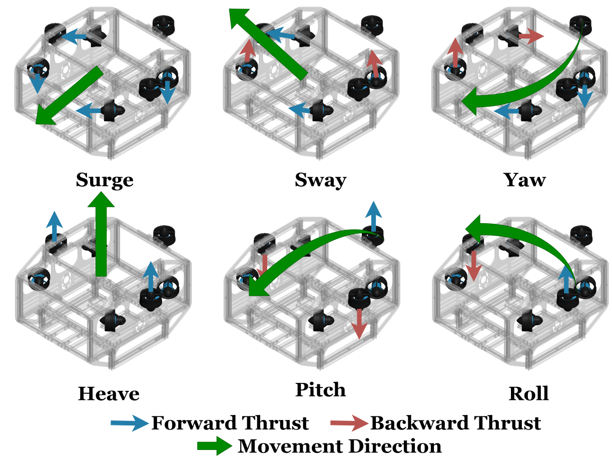


Figure 9: Kamikaze's Degrees of Freedom.

Trade-offs in Thruster Selection

- **Power vs. Performance:** More thrusters improve stability but increase power consumption. Seven thrusters provide a balance between efficiency and control.
- **Cost vs. Mission Needs:** Reusing last year's T200 thrusters reduces costs while still meeting competition requirements.

2.3.1.3 Buoyancy and Stability

Something about buoyancy and stability. Lorem ipsum dolor sit amet, consectetuer adipiscing elit. Ut purus elit, vestibulum ut, placerat ac, adipiscing vitae, felis. Curabitur dictum gravida mauris. Nam arcu libero, nonummy eget, consectetuer id, vulputate a, magna. Donec vehicula augue eu neque. Pellentesque habitant morbi tristique senectus et netus et malesuada fames ac turpis egestas. Mauris ut leo. Cras viverra metus rhoncus sem. Nulla et lectus vestibulum urna fringilla ultri-

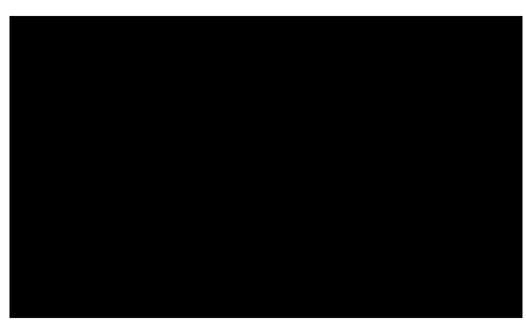


Figure 10: Flow Simulation.

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Figure 11: Buoyancy.

2.3.1.4 Main Canister

The canister serves as the primary enclosure for the ROV, protecting essential components such as microcontrollers, power systems, and sensors while ensuring pressure resistance, corrosion protection, and ease of maintenance. The design consists of a 3D-printed PETG body, an aluminum base, and a PETG lid with embedded acrylic windows, providing structural stability and waterproof integrity under operational conditions.

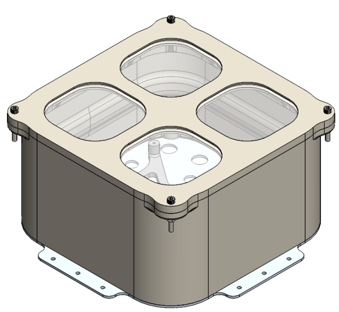
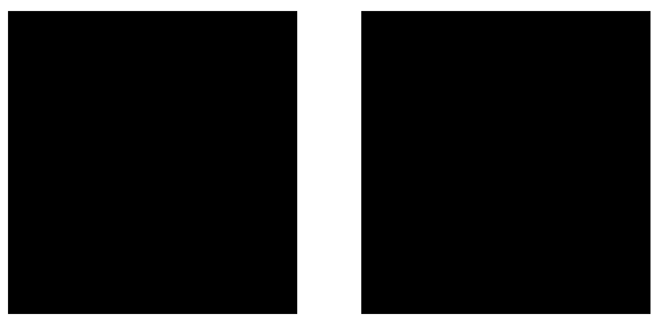


Figure 12: Kamikaze's Main canister.

PETG was chosen as a cost-effective alternative to aluminum, offering a balance between mechanical strength and manufacturability. Although PETG is inherently waterproof, Sikadur®-31 CF sealant was applied to enhance structural integrity and reliability. The 3mm-thick aluminum base provides structural support for bulkhead glands, preventing layer separation and ensuring durability. The canister dimensions are 276×276×142.59 mm, optimized for component housing and pressure resistance. A three-stage sealing process was implemented, consisting of mechanical fastening, epoxy bonding, and polyurethane sealant, to maintain a watertight enclosure. The removable PETG lid, secured with M5 screws and dual O-rings, allows for easy inspection and maintenance, while four embedded acrylic windows provide visual access without disassembly.

To evaluate structural performance, a Finite Element Analysis (FEA) was conducted:

- **Top View (Figure 13a):** Stress is concentrated around circular openings and edges, which experience higher mechanical loads from water pressure.
- **Bottom View (Figure 13b):** Bolted connections and interface zones between the base and side walls accumulate stress, making them susceptible to deformation.



(a) Top View Analysis. (b) Bottom View Analysis.

Figure 13: Main Canister Finite Element Analysis.

2.3.1.5 Sealing Strategy

Waterproofing is critical for the ROV's performance and durability. The sealing approach protects electronic components while maintaining structural integrity under varying pressures. This design integrates 3D-printed PETG, aluminum, high-performance adhesives, and mechanical fasteners for optimal sealing efficiency.

Main Canister Sealing (Electronics Housing)

- Sikadur-31 CF adhesive prevents micro-gaps.
- IP68-rated metallic cable glands ensure watertight cable entry.
- Epoxy resin & super glue reinforce adhesion.
- Bolted fastening ensures long-term stability.

ZED Camera Enclosure

- O-ring in a groove forms a primary seal.
- RTV Gasket Maker provides additional waterproofing.
- Compression sealing & Allen bolts apply uniform pressure.
- Sikadur-31 CF protects against water exposure.

Artelon Camera Enclosures

For other cameras, Artelon enclosures replace aluminum.

- Acrylic cover sandwiched with an O-ring seal ensures water resistance.
- Allen bolts provide tight compression for long-term sealing.

Bolt Spacing Calculation for Optimal Sealing

To ensure optimal sealing pressure and prevent gasket deformation under load, the bolt spacing (C) is calculated based on flange stiffness, gasket pressure, and deflection using equation 2.

$$C = \left[\frac{480 \left(\frac{a}{b}\right) E t^3 \Delta H}{13 P_{\text{min}} + 2 P_{\text{max}}} \right]^{1/4} \tag{2}$$

where:

- C = Bolt spacing (mm)
- a = Width of the flange plate (mm)
- b = Width of the gasket (mm)
- E = Modulus of elasticity of the flange material (Pa or N/m^2)
- t = Thickness of the flange (mm)
- ΔH = Max. gasket deflection - Min. gasket deflection (mm)
- P_{min} = Minimum gasket pressure (Pa or N/m^2)
- P_{max} = Maximum gasket pressure (Pa or N/m^2)

2.3.1.6 Cameras

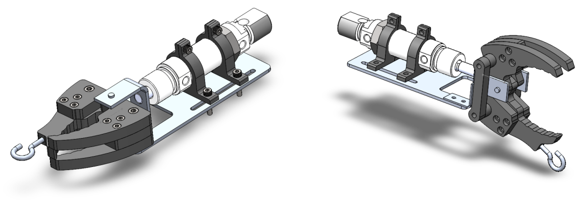
Something about cameras. Lorem ipsum dolor sit amet, consectetuer adipiscing elit. Ut purus elit, vestibulum ut, placerat ac, adipiscing vitae, felis. Curabitur dictum gravida mauris. Nam arcu libero, nonummy eget, consectetuer id, vulputate a, magna. Donec vehicula augue eu neque. Pellentesque habitant morbi tristique senectus et netus et malesuada fames ac turpis egestas. Mauris ut leo. Cras viverra metus rhoncus sem. Nulla et lectus vestibulum urna fringilla ultrices. Phasellus eu tellus sit amet tortor gravida placerat. Integer sapien est, iaculis in, pretium quis, viverra ac, nunc. Praesent eget sem vel leo ultrices bibendum. Aenean faucibus. Morbi dolor nulla, malesuada eu, pulvinar at, mollis ac, nulla. Curabitur auctor semper nulla. Donec varius orci eget risus. Duis nibh mi, congue eu, accumsan eleifend, sagittis quis, diam. Duis eget orci sit amet orci dignissim rutrum.

Figure 14: Cameras.

2.3.1.7 Grippers

Two claw grippers (Figure 15) are designed to handle various item shapes and diameters. They are constructed from 10mm HDPE for durability and aluminum for fixation, ensuring a lightweight yet sturdy design. The grippers are pneumatically actuated using a 25mm stroke piston that applies 113–135N of force in both forward and backward directions. With a maximum opening width of 70mm, they can securely grip all required competition objects.

To enhance functionality, two screw hooks were integrated, enabling the ROV to lift hooks and manipulate ropes, expanding its operational capabilities.To optimize the gripper's design and prevent potential bending

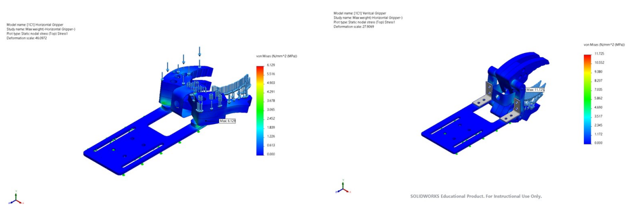


(a) Horizontal Gripper. (b) Vertical Gripper.

Figure 15: Kamikaze Grippers.

stress-induced failures, a comprehensive stress analysis was performed. This theoretical evaluation ensured the gripper's ability to withstand the designated weight. The results 16confirmed that:

- The horizontal gripper can hold up to 14.6 kg.
- The vertical gripper can hold up to 11.8 kg.
- Both with a safety factor of 2.



(a) Horizontal Gripper Analysis. (b) Vertical Gripper Analysis.

Figure 16: Kamikaze Grippers Analysis.

2.3.2 Electrical System

2.3.2.1 Control Units

(i) **Topside Control Unit**

The Topside unit is where the pilot and the main program function. Several components are used to make up the topside control unit, which are shown in table 1.

Station Component	Function
Logitech G Extreme 3D Pro Joystick	Used for controlling the ROV's motion.
Laptop	Used for displaying all information received from the underwater unit.
Power Source	Provides 48V operating voltage and a current maximum rating of 30A.
Compressor	Used for supplying compressed air to the ROV's manipulator.
Monitor	Used for displaying video feeds from the ROV
Router	Used for establishing a wired connection between the ROV and the topside control unit.
Anderson connector	A type of electrical connector used for connection power to the ROV

Continue on the next column

Table 1: ROV Station Components and Functions

Table 1: ROV Station Components and Functions

For efficient control and communication between the topside control unit and the ROV, the components found in Table 2 are used in the vehicle.

Vehicle Component	Function
T200 Thrusters with ESC	Thrusters used for controlling the ROV's motion, including the Electronic Speed Controller (ESC)
48V to 12V DC-DC Converters	Converts the operating 48V to 12V
Raspberry pi 5	A powerful microcontroller used for processing and controlling the ROV
STM32	A microcontroller board used for controlling various functions of the ROV
1080p USB wide-angle Cameras	Providing high quality footage for tasks like navigation and 3D modelling.
720p USB camera	Providing footage from sides of the vehicle.
Zed 2i stereo camera	Depth camera that captures 3D images, generates depth maps
W5500 Ethernet module	For real-time system monitoring and debugging
CAN bus module	Ensures efficient and reliable communication between nodes

Table 2: Vehicle Components and Functions

(ii) **Sensors**

To provide the necessary data to control the ROV, different sensors are used, each for the different parameters. The sensors used can be found in the following table 3.

Sensor	Function
Custom depth sensor (MS5837)	Measuring underwater pressure and depth level of the vehicle
Arduino Nano RP2040 IMU	Measuring the angular velocity and linear acceleration of the vehicle

Continue on the next column

Table 3: ROV Sensors and Functions

Voltage & Current Sensors (ACS712)	Track power consumption

Table 3: ROV Sensors and Functions

Implementation of a Custom-Designed Depth Sensor

A custom-designed depth sensor was introduced to replace the previously existing board. The new sensor delivered greater accuracy, Realtime measurements, and supported a wider range of connectivity options. This upgrade significantly improved system performance and reliability, ensuring precise and efficient depth measurement.

(iii) **Underwater Control Unit**

The Vehicle components are all mounted on 2 meticulously designed PCBs for maximum efficiency and low space consumption, connecting all the microcontrollers and the sensors inside the ROV.

(iv) **System Integration**

The ROV's electrical system is interconnected through a structured communication framework. At the top side, the joystick sends control signals to the laptop, which transmits them to the router and then down the tether via an Ethernet cable. On the ROV side, an Ethernet switch distributes the signals, directing one output to the Raspberry Pi 5 (the primary controller) and another to the W5500 Ethernet module.
The system is designed as an integrated network of three modular subsystems. The Power Subsystem houses Electronic Speed Controllers (ESCs) and an STM32 microcontroller. The Raspberry Pi 5 sends control signals to the STM32 board, which then controls the seven ESCs connected to their respective T200 thrusters. Additionally, the STM32 microcontroller continuously collects real-time power consumption data of the thrusters and power converters, including current and voltage readings from the ACS712 current sensor, and transmits it to Raspberry Pi 5 via the CAN bus module for monitoring and analysis. The second subsystem is The Sensor System which includes the depth sensor and an Arduino Nano RP2040 for the IMU readings, both of which are connected to an STM32 microcontroller that handles data acquisition. STM32 processes the sensor data and sends it to Raspberry Pi 5 via the CAN bus protocol, ensuring timely and reliable data transmission. Finally, the Debugging subsystem which consists of an Ethernet module connected to an STM32 microcontroller, interfaced with the network switch via an Ethernet cable. Through CAN bus integration, the Ethernet module communicates with the other subsystems. Ables real-time system debugging, allowing for troubleshooting of the entire system remotely. It also provides fault control, monitoring and managing any failures that may occur within the Power PCB or Sensor subsystem. Finally, the camera's video feed is processed by the Raspberry Pi 5, transmitted back to the topside through the tether, and displayed on the GUI on the laptop. Additionally, all other sensor data, including depth measurements, current and voltage values from the Power PCB, and IMU from the Arduino Nano RP2040, are collected by the STM32 microcontrollers and sent to the Raspberry Pi 5 via CAN bus. The Raspberry Pi then transmits this information via ROS to the topside control station, where it is displayed on the GUI for real-time monitoring.

2.3.2.2 Electric Power

The provided power is 48 V and with a maximum of 30 A. This power needs to be converted and well distributed to suit our needs in the ROV, as powering the thrusters, ESCs, vision system, development boards, and other peripherals.

(i) **Power Conversion System**

The 48-Volt supply voltage is converted into 12 V using five different DC-DC Step down converters. Four of the converters provide a current of 30 Amps, and the fifth one provides 10 Amps. The total current is then distributed to the thrusters and the power unit PCB to supply power to the other boards inside the canister. In addition, there are Four 12V-to-5V step-down (buck) converters inside the power unit PCB, two of them provide 5 Amps for the Raspberry Pi board. The other twp provide 3 amps, one of them supplying STM32 microcontrollers and the CAN bus modules in the power PCB while the other supply the sensors and other indicators. Details of power distribution can be seen in Table 4.

Component	Quantity	Voltage (V)	Current (A)	Power Per Unit (W)	Total Power (W)
T200 Thruster	7	12	12	144	1008
Basic ESC	7	12	0.15	1.8	12.6
Raspberry Pi 5	1	5	5	25	25
STM32	4	3.3	0.125	0.4125	1.65
MCP2515 CAN Bus Module	5	5	0.1	0.5	2.5
W5500 Ethernet Module	1	5	0.13	0.65	0.65
Arduino Nano RP2040	1	5	0.45	2.25	2.25
720p USB Camera	3	5	0.2	1	3
1080p USB camera	2	5	0.275	1.375	2.75
MS5837 Depth Sensor	1	5	0.002	0.01	0.01
ZED 2i stereo camera	1	5	0.5	2.5	2.5
Total					**1060.91**

Table 4: Power Calculation for the ROV.

Total Current Drawn at 48V: $1060.9/48 = 21.10\,\text{A}$,
Applying Safety Factor: $1.3 \times 21.10 = 28.73\,\text{A}$
Required Fuse = 30A

(ii) **Power Unit**

As mentioned above, two PCB containing three subsystems were designed specifically for the power conversion system inside the ROV.

2.3.2.3 Tether

The tether is made of Polyethylene terephthalate (PET) light weight 15mm expandable cable sleeve which provides protection for the cables inside (Figure 17). Tether length is 25 meters long and consists of two 16mm2 cables made from Aluminum and PVC jacket material. CAT6e for ethernet communication. The 2 pneumatic hose supply is also included in the tether, one as an inlet and the other as an outlet.

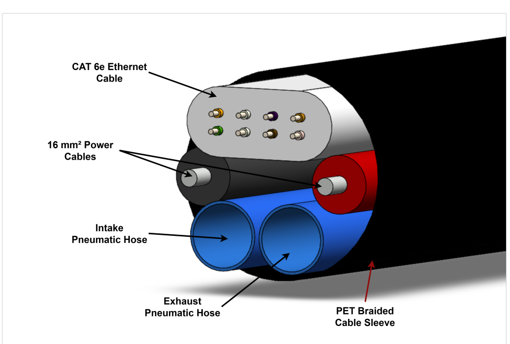


Figure 17: Tether Cross Section.

2.3.3 Software System

2.3.3.1 Communication System

The ROV's communication architecture which is illustrated in Figure 1 can be divided into two parts: the top side control unit and the ROV unit.

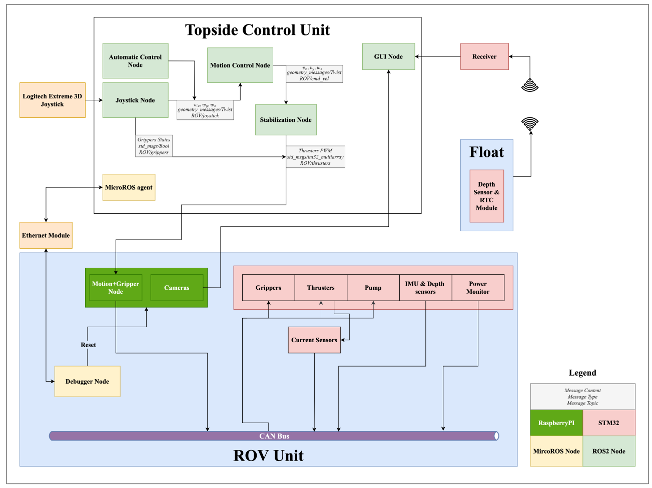


Figure 18: Communication architecture

System Evolution and Communication Backbone

In last year's architecture, we utilized ROS 1 as the main framework for communication between the control unit and the ROV's micro-controllers.

Communication with MCUs was handled through `rosserial`, which introduced a critical limitation: the presence of a single point of failure—the ROS Master. Any instability or failure in the master would cause the entire system to halt, making it unreliable in underwater environments where robustness is essential.

This year, we have transitioned fully to ROS 2, eliminating the dependency on a centralized master. Communication between the topside control unit and the ROV unit is now handled using ROS2 & CAN communication, which is more reliable, scalable, and real-time capable.

In parallel, we've integrated `micro-ROS` to run a debugger node on the ROV side. This node communicates with the topside unit via an Ethernet module, acting as a backup communication path. In the event of failure of our SBC—the Raspberry Pi, this channel ensures continued monitoring of the entire system's vitals which greatly facilitates debugging in case of a problem with our system.

This upgraded architecture enhances reduces the risk of total system failure, making it far more suitable for mission-critical underwater operations and industrial applications.

Topside Control Unit The topside control unit hosts the nodes and agents that work above water which includes:

- Joystick Node
- Automatic Control Node
- Stabilization Node
- Motion Control Node
- GUI Node
- Micro-ROS agent

Data is received from the following streams:

- Camera feed from the ZED camera as well as the side-assisting cameras
- Readings from sensors which includes an IMU sensor and a depth sensor
- Readings from the joystick
- Receiver from the Float unit

The joystick node is interfaced with the Logitech Extreme 3D Pro Joystick, capturing signals and converting them into ROS messages, which then are sent over to the motion control node in order to order to convert these signals to motion vectors and gripper operations.
For autonomous tasks, the automatic control node is pivotal. It receives commands from the joystick and autonomously sends out commands to the motion control node.
The motion control node converts the received messages into motion vectors that are then sent to the stabilization node.
The stabilization node is used to maintain the operational stability of the ROV by applying various PID controllers to counter any disturbances.
The GUI node acts as the pilot's interface, displaying camera feeds for navigation as well as displaying the ROV's vitals.
Vitals include:

- IMU readings
- Depth readings from both the ROV unit and the Float unit
- Thrusters PWM values

ROV Unit The ROV unit is where a lot of the heavy lifting happens, it executes commands received from the topside control unit, streams cameras and hosts the debugger node.
The ROV unit has a Raspberry Pi 5 that's responsible for streaming cameras to the GUI node as well as it hosts a ROS 2 node that is responsible for receiving the commands from the stabilization node.
Connected to the Raspberry Pi 5 is the CAN bus where it receives data from sensors such as current sensors, a depth sensor, an IMU and the power monitor. That are then published to both the topside control unit as well as the debugger node.

Float Unit The float unit hosts a depth senor that transmits it's readings using an NRF transceiver module and an RTC (Real-time Clock) to the receiver which are then displayed on the GUI in the topside control unit.

2.3.3.2 Graphical User Interface

Our GUI prioritizes stability, usability, and responsiveness, balancing personalization with default configurations. Built with Python and PyQt5, it ensures a stable and efficient desktop experience.

System Architecture The GUI follows a modular design, dividing functionality across four interfaces: Pilot, Copilot, Engineer, and Float. This enhances maintainability while tailoring tools to each role.

Pilot Interface Designed for minimal clutter, the Pilot interface displays five camera feeds essential for navigation. To ensure smooth streaming, we use Python's `Multiprocessing` library, preventing latency and glitches. The Pilot can switch views and resize feeds as needed. Our redundant streaming system prevents a single point of failure—if one camera disconnects, others remain functional.

Copilot Interface The Copilot interface extends camera controls, allowing real-time brightness, contrast, and backlight adjustments for varying underwater conditions. It also displays telemetry data, including six degrees of freedom (Vx, Vy, Vz, Roll, Pitch, Yaw), depth, and thruster speeds, aiding in system monitoring and troubleshooting. A screenshot of the interface is shown in Figure 19.

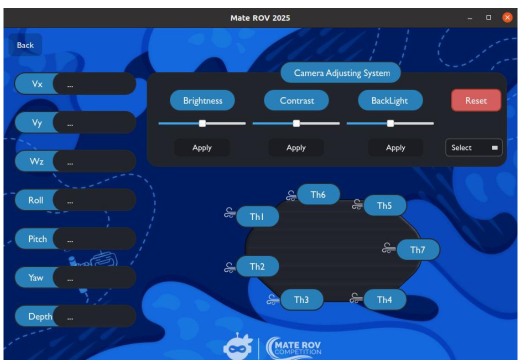


Figure 19: Screenshot of the Copilot interface.

Engineer Interface The Engineer interface provides quick access to automation scripts for tasks like invasive carp detection and depth estimation. It also facilitates seamless media capture for Photosphere documentation. All functions are integrated within the GUI, streamlining workflow without external tools. A screenshot of the interface is shown in Figure 20.

Float Interface The Float interface enables communication with the float before vertical profiling begins and displays depth data along with additional metrics post-profile.

2.3.3.3 Kinematics

The Kamikaze's movement underwater may be one of the most important aspects of the design. We had to ensure stability, maneuverability, and speed. We achieved

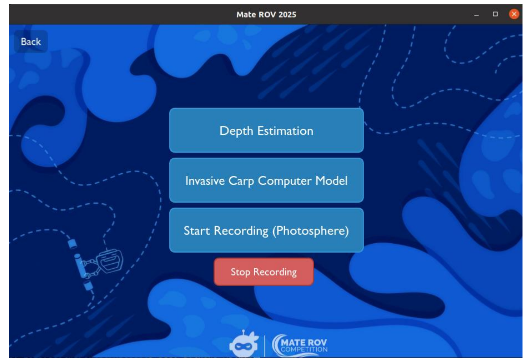


Figure 20: Screenshot of the Engineer interface.

this by focusing on two main aspects:

- **Thrusters Configuration:** We employed a seventh thruster this year to improve the robot's maneuverability as shown in figure 21. With the current vectored thrusters configuration and this new thruster, we can achieve motion in 6 degrees of freedom. This novel configuration may be the first of its kind to allow for such a wide range of motion while only using 7 thrusters.

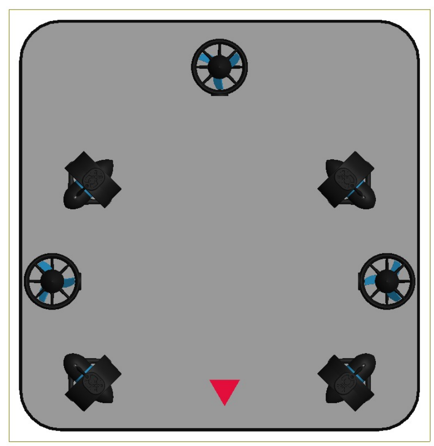


Figure 21: Thruster Configuration

- **PID Control:** We have implemented PID controllers for all critical movement axes, allowing for precise control over the robot's movement and ensures that it remains stable in the water. We implemented an FFT (Fast Fourier Transform) based auto-tuning algorithm to tune the PID parameters, as this is our first year using the new Vehicle. We also supplemented the algorithm with a live plotting feature, shown in figure 22, to allow for manual adjustments to the PID parameters.

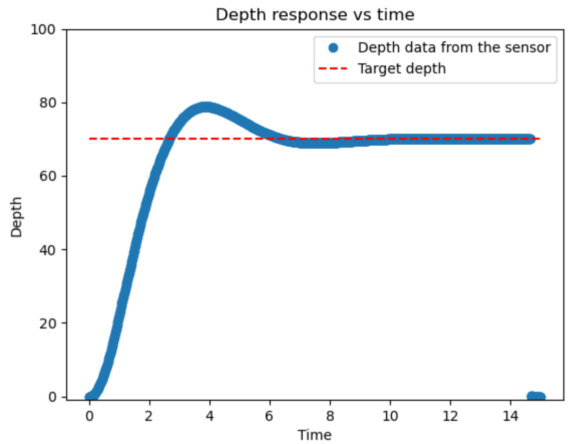


Figure 22: Live Plotting of PID Parameters

2.3.3.4 Open Sourcing the Kamikaze

We have all of our working code available on our GitHub repository. A lot of effort was made this year to maintain, document, and clean up the code, making it easier for future teams to understand and build upon. We believe that this is a crucial step in the development of the Kamikaze, as it allows for a more collaborative environment and ensures that the knowledge gained from each year is not lost.

2.3.3.5 Some third point

2.4 Mission Specific Auxiliary Tools

2.4.1 Stabilizing Cap Positioning Extension

One of the specialized systems developed for Kamikaze is the Stabilizing Cap Positioning Extension (SCPE). While Kamikaze installs a new thermistor, the SCPE (Figure 23a) secures the thermistor cap in place, ensuring perfect alignment.

The mechanism's smooth and controlled extension is provided by a telescopic ball-bearing slide, which is like those found in drawer runners. A 2.5-inch diameter cup at the top provides a little amount of alignment tolerance, guaranteeing a firm but flexible hold on the cap.

The extension lengthens as the SCPE holds onto the cap and Kamikaze lowers, keeping the cap in place. The extension shrinks as Kamikaze rises with the thermistor, holding the cap firmly in place and facilitating a smooth hookup.

2.4.2 Liquid Sample Acquiring System

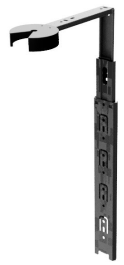
To enable efficient and flexible liquid sample collection, a modular design approach (Figure 23b) was implemented. This design allows for straightforward assembly, disassembly, and maintenance of individual components, thereby improving both convenience and system reliability during the sampling process. To further ensure optimal functionality under high-pressure conditions, the system incorporates a mini pump with a flow rate of 80 L/h, which was tested underwater to validate its performance. Additionally, a collection bottle featuring a user-friendly disassembly mechanism was integrated, easing the sample retrieval process and confirming its compatibility within the overall system.

2.4.3 Jelly Collecting Shutter Mechanism

A specialized mechanism has been developed to collect and transport a jelly-like object filled with water to the surface. The system consists of a sealed acrylic tube, closed at the top, with a pneumatically controlled shutter at the bottom. When the pilot successfully guides the jelly inside the tube, the shutter activates, preventing it from drifting away while allowing water to flow freely. This design (Figure 23c) ensures that the jelly remains contained within the tube as it ascends due to buoyancy, enabling controlled and efficient transport to the surface.

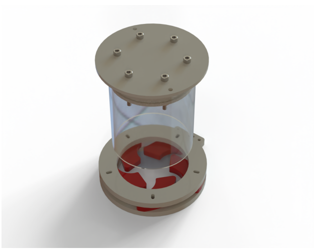
2.4.4 Customized Hook

A customized hook mechanism has been developed to efficiently collect chenille strips (pipe cleaners) from the water surface. Since the strips float on the surface, they cannot be gripped using the ROV's main gripper. Positioned at the top of the ROV, the hook (Figure 23d) is strategically designed to maximize the number of strips gathered in a single attempt. To further enhance the mechanism's effectiveness, Velcro can be added to ensure the strips stick within the hook securely. This design improves the ROV's efficiency in completing the task, ensuring a higher collection rate.

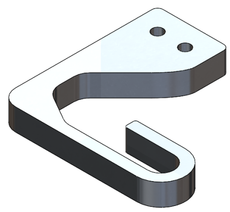


(a) Stabilizing Cap Positioning Extension.

(b) Liquid Sample Acquiring System.



(c) Jelly Collecting Shutter Mechanism.



(d) Customized Hook.

Figure 23: Kamikaze's Mission-Specific Tools.

2.4.5 Vertical Profiling Float

EJUST Robotics Clun supports the National Science Foundation (NSF)-funded GO-BGC project's mission to build a global network of chemical and biological sensors for ocean health monitoring. As part of this initiative, our team has developed Fat Man, a vertical profiling float designed for ocean observation and data collection. This float enhances the ability to monitor key environmental parameters, providing valuable insights into ocean dynamics and contributing to global research efforts on climate change.

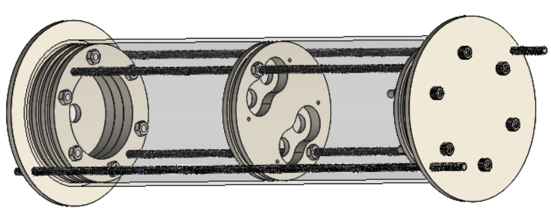


Figure 24: E-JUST Vertical Profiling Float, Fat Man.

Fat Man is constructed from transparent acrylic, allowing visual inspection and error detection, and is divided into two sections by an HDPE disk to separate the electrical components from the water chamber. A suction system with peristaltic pumps enables precise buoyancy control by regulating water intake and release. The electrical system, powered by an STM32 microcontroller, integrates a depth sensor, motor driver, and NRF24L01 radio module for real-time data collection and transmission. Supported by NiMH batteries, the system ensures stable operation, reinforcing EJUST Robotics Club's commitment to advancing ocean research and technology.

3 Safety

3.1 Safety Philosophy

At E-JUST Robotics Club, safety is the foundation of every aspect of Kamikaze ROV's design, construction, and operation. We are committed to preventing injuries, protecting equipment, and ensuring a secure working environment for all team members.

Figure 25: Cutting the PVC pipes for the training track assembly.

3.2 Workshop Safety

The E-JUST Robotics Club recognizes the potential dangers and hazards inherent in assembling robotics, whether mechanical or electrical. Consequently, the club has put in place strict safety procedures to ensure the security of every member. In addition, a variety of safety gear is provided in the workshop, such as soldering fume extractors, protective gloves, and face guards. All operations are supervised by a professional safety director who makes sure that the extensive safety checklist found in Appendix B is strictly followed.

3.3 Safety Training

In addition to receiving technical instruction, new members receive extensive safety training from experienced peers. All members acquire expertise in the procedures required to always guarantee safety through com prehensive safety training and hands-on experience obtained in a supervised environment.

3.4 Kamikaze Safety Features

Safety remains a top priority for the E-JUST Robotics Club, which is reflected in the design and production of Kamikaze. In compliance with MATE Organization requirements, a properly sized fuse is installed at the Anderson connectors. Strain relief is applied at both ends of the tether to prevent stress on connectors and ensure uninterrupted communication.

All bolts are securely covered, and the frame is carefully sanded to eliminate sharp edges. Kamikaze's thrusters are equipped with protective shrouds (Figure 26) to enhance operator and handler safety. Additionally, its manipulators and auxiliary equipment feature extra safety measures, with Neoprene coverings ensuring a firm grip while preventing damage to nearby objects during transportation.

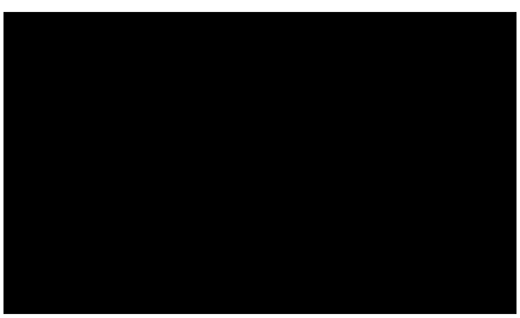


Figure 26: Shrouded Thrusters.

Each thruster operating in the aquatic environment is protected by a fuse to minimize electrical shock risks and prevent damage. For efficient heat dissipation, converters are positioned outside the canister and fully insulated, while heat-conducting components inside the canister are attached to its walls to create a heat sink effect. This design effectively manages temperatures and ensures optimal system performance.

3.5 Safety Checklist

All members participating in Kamikaze's deployment must follow a strict safety procedure enforced by the E-JUST Robotics Club. Routine inspections are conducted, and Appendix C outlines a comprehensive operating safety standard. While all members are responsible for adhering to the safety checklist, its strict implementation is supervised by a trained safety director.

4 Testing and Troubleshooting

5 Logistics

6 Conclusion

7 Appendix