Technical Report 2025 – U.Stall

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1. Abstract

Remotely Operated Vehicles (ROVs) are becoming more and more crucial tools in scientific research and industrial applications. To learn more about this technology in the underwater world, U.Stall was established at Esslingen University of Applied Sciences in September 2023.

Now in our second year, we do not come with just ambition, but also the shared experience that we gained from our first attempt at the MATE ROV Competition. With renewed resolve and greater insight, we have honed our plan and incorporated lessons learned previously into our present ROV design.

Our ROV, named Louis in honor of our main sponsor Louis Schuler Fonds, has a distinctive appearance made up of a triangular motor orientation and its 2-Box System. This unique appearance allows for modular integration of tools, low weight, efficient movement in all 6 Degrees of Freedom while providing independent functionality between both subsystems.

Modular and high-performance in design, Louis has multifunctional instruments that can be used for observation, sampling, and restoration tasks. We believe it's a helpful instrument for scientists and professionals engaged in delicate underwater environments.

This project has allowed us to push our engineering skills a notch higher while assisting in developing a cleaner, healthier underwater environment. Through dedication and collaboration, we remain committed to using technology for biodiversity conservation and developing sustainable underwater solutions.

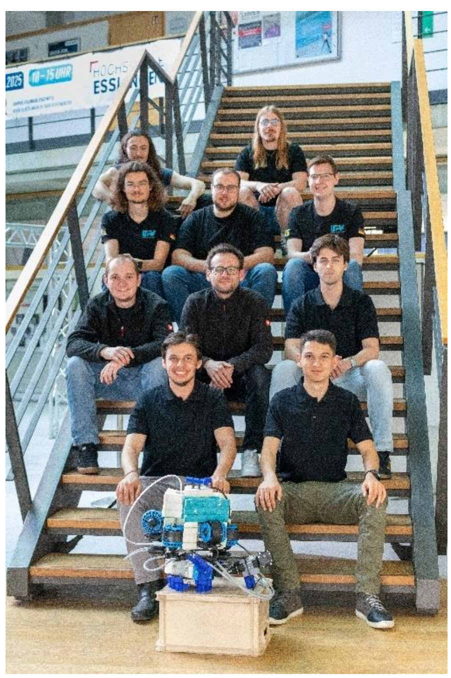

Figure 1: Picture of U.Stall Members with their newest ROV "Louis".

2. System Overview

Our ROV system is designed with modular **architecture**, distributed across three functional levels: the **Surface Workstation**, the upper **Navigation Module**, and the lower **Tool Module**. This clear separation of control, actuation, and sensor logic provides high flexibility, ease of debugging, and supports rapid tool development.

At the heart of our concept is the ROV's **distinctive triangular shape**, inspired by the design philosophy of Franz Reuleaux. This geometry is not only aesthetically unique but also technically advantageous:

- The **three-dimensional symmetry** enables stable movement in all directions.
- The **placement of six thrusters** around the triangle allows for precise translation and rotation in any axis (surge, sway, heave, roll, pitch, yaw).
- The **compact triangular frame** simplifies buoyancy control and reduces structural weight.

The **Navigation Module** houses the **motor control subsystem**, where a **Raspberry Pi Pico** interfaces with six Electronic Speed Controllers (ESCs) to drive the thrusters. An onboard **gyroscope** and **magnetometer** support orientation tracking, while a **UART interface** enables high-speed communication with the Surface Workstation.

The **Tool Module** focuses on tool actuation and sensor integration. A **Raspberry Pi 5** serves as the main processor, interfacing with cameras, gripper servos, and environmental sensors. Two microcontrollers – an **ATMega** and a **Pi Pico** – control various gripper tools, including articulated arms and a water pump. All tools connect via a **modular backplane system**, ensuring hot-swappable tool integration.

Three wide-angle **USB cameras** are connected to the Pi and enclosed in custom waterproof housings, providing near-360° situational awareness. Camera positioning was optimized using virtual simulation and real-world testing.

The **Surface Workstation** consists of laptop running control software, connected to a **gamepad controller** for user input. Data exchange with the ROV is achieved via **Ethernet** and a **UART-to-USB bridge**, ensuring robust and real-time communication.

This layered and modular structure allows the ROV to adapt to a wide range of tasks – from precise manipulation using custom tools to responsive movement in complex underwater environments. Through clear interface separation, component redundancy, and streamlined communication paths, our system is not only powerful but also maintainable and extensible for future teams.

3. Mechanical Subsystem

3.1. General Mechanical Design

The fundamental goal of the ROV is to offer customers and end users maximal flexibility and repairability, whilst keeping the weight as well as the physical footprint down.

To accomplish this, the vehicle is split into two separate modules:

- **Navigation Module:** Providing propulsion and maneuvering.
- **Tool Module:** Hosting all sensors and actuators required for completing tasks.

These two modules can easily be separated through 3 pins and two connectors, giving customers the ability to prepare multiple different configurations of the exploration module and swapping them out quickly. Through this separation of systems, the ROV can return to operations after an accident faster, as in most cases only one module would have to be replaced / repaired.

Each module consists of a central chassis box containing the required electronics for the module while also protecting the electronics from water and other environmental influences.

The chassis boxes are machined from solid 5083 aluminum, as it is a proven maritime alloy, and comprise either three parts (tub, sleeve, and lid) or two parts (tub and lid). The box parts are sealed through a 2mm O-ring in between each interface.

As a second system to achieve our desired levels of modularity, we decided to attach all thrusters and task-modules like cameras through our self-developed **Common Interface**. It consists of a female and a male part, which are inspired by dove-tail joints, but have their usually parallel walls at an angle, so by tightening the alignment screw, the connection is pulled together tighter and able to counteract manufacturing tolerances, making these parts cheap. Failed thrusters or different task-elements can be connected / disconnected through a single screw and electrical connector.

After considerations on possible task-elements, it was decided 6 Common Interfaces would suffice, so the 6-side layout of the thrusters was reused to keep development efforts limited. Additionally, the number of connectors and their pin count was chosen based on a worst-case scenario for the amount and requirements of task-elements.

As an example, for creating a photosphere specialized cameras with specific orientation are required. Our Common interface system allows a user to mount up to 6 of those cameras and set them up. Should the user require to have a gripper mounted to the ROV right after taking the photosphere, they can simply dive back to the launch area, remove the unnecessary cameras and attach the gripper. Where with different ROV designs this may take a long time, if possible, at all, our design allows this pitstop to last even under a minute.

To ensure the vehicle is buoyant and is easy to pilot, we added volumes made from polystyrene plates situated at the top of the vehicle and a steel plate at the bottom. As the polystyrene plates are one of the most fragile parts of the ROV, they are connected through a Common Interface to the Navigation Modules Lid, making it a quick and easy thing to change them.

The decision to develop the whole chassis and all mechanical connectors in house was made after a long discussion on cost-effectiveness compared to purchasing an off-the-shelf electronics box. The choice in Favor of a self-developed chassis in the manner outlined above was made for two reasons.

On the one hand, as we combined mechanical elements required for containing the electronics and for the ROVs structural integrity, we were able to stay as weight efficient as possible and, taking the requirement for a buoyant vehicle into account, keeping the required volume equally low.

On the other hand, going all the way of developing our own modular chassis at this point gives us a ROV, which's basis does not need to be reengineered for coming seasons, and is going to require us only to develop new task-elements as we get presented with new tasks.

However, for cost effectiveness reasons, we chose to purchase **Soureau connectors** as they are a proven system and are not at odds with our vision of a modular ROV.

The boxes, as well as the Common Interface have been verified in the structural integrity and dimensioning by Finite Element Analysis using loads intentionally far exceeding any load experienced during the ROVs deployment. The geometry of e.g. grooves for O-Rings follow industry standard recommendations and the bolts for the Soureau UTSX Connectors use an OEM-recommended torque spec. To keep track of the buoyancy of the vehicle, a table was used, denoting the weight and volume of every major part.

3.2. Gripper No.1

Modular, Waterproof, and Mechanically Optimized:
This year's ROV features a completely redesigned, modular gripper system driven by three servo motors. The gripper enables three main functions: vertical movement (up/down), rotation along its longitudinal axis, and the opening and closing of the claw mechanism. The design goal was to improve precision, reliability, and maintainability during underwater operations.

Design Decisions & Innovations:
Based on lessons learned from previous years, we decided to take additional waterproofing measures—even though the servo motors are rated as waterproof by the manufacturer. Each motor is enclosed in a custom resin-printed housing, chosen for its:
- Inherent waterproof properties due to the material
- Cost-effectiveness and design flexibility through 3D printing

Sealing was accomplished using two techniques:
- Cable entries were sealed using epoxy adhesive
- Rotating shafts were sealed using dual O-rings

Mechanical structures and supports that do not require waterproofing were produced using FDM 3D printing, optimizing for strength, ease of manufacturing, and cost.

Mechanical Support through Springs:
To reduce the load on the servo responsible for vertical motion, two return springs were added. These helps counteract the weight of the gripper, improving energy efficiency and minimizing mechanical stress during operation. This extends the system's operational life and increases reliability.

Build-vs.-Buy Decisions:
We chose to design and encapsulate the gripper system in-house for several reasons:
- Commercial underwater servos are often non-modular, expensive, or difficult to integrate
- Our custom solution allowed for better integration with the ROV's compact tool-sled and mechanical structure

Testing & Safety Strategy:
Each servo was first tested individually in a submerged test tank under real-world conditions before being integrated into the full assembly. The custom enclosures were also pressure-tested to detect leaks before full deployment. Safety measures included cable strain relief and sealed housing to prevent short circuits and water ingress during extended missions.

Modularity & System Integration:
The gripper is mounted on the tool-sled layer of the ROV and can be removed or replaced within minutes. It is controlled via dedicated PWM lines connected to the Tool Control Unit (TCU). No software changes are needed, making the system plug-and-play compatible with the existing ROV architecture. This design also supports future upgrades such as additional sensors or camera modules attached to the gripper.

3.3. Gripper with Pump

The gripper arm consists of three large parts: two rods and an adapter. It is driven by three servomotors. Two of the motors are mounted on the front rod, which is attached to the ROV with a bolt. A rack is also attached to the ROV with a bolt, and a motor is mounted on it. Each motor drives a shaft that moves a gear wheel. The servomotor can perform a maximum rotation of 180°. The rotation of the gear wheel moves a toothed rack, which is attached to the upper or lower end of the front arm with a bolt. Depending on the rotation, the arm tilts or lifts to the desired position. Each individual part of the arm can be moved thanks to the clear separation and the individual servomotors. This prevents the ROV from needing to be realigned or moved if the tool is not positioned precisely over the hole.

An adapter is attached to the front part of the gripper arm, which can also be moved by a servomotor. This allows for corrections without moving the arm or the ROV, for example, if the tool is not flush with the outflow opening and prevents the liquid to be measured from leaking out. The respective tool required for processing individual subtasks can be screwed into the adapter and, depending on the field of activity or task, can be changed quickly if necessary. The built-in tool is therefore only attached using two screws. This has the advantage that the arm can be used universally, with the focus placed on the development and design of the individual tools.

To minimize repair time in the event of a mechanical issue, the goal is to build with as few different parts as possible. Another advantage is that fewer parts need to be transported. In the first design of the gripper arm, cylinders with an extendable piston were used. Since these would have had to be operated either pneumatically or hydraulically, requiring the ROV to undergo additional testing, they were replaced by electrically operated servomotors. Furthermore, the cabling and control of the motors are easier to implement. The piston was replaced by the rack and gear wheel construction.

A box is attached to the adapter for measuring the liquid sample. It is divided into two parts. There is a hole on the top of the box from which a measuring probe protrudes. It is connected to the ROV via a cable and transmits the measured values. A blunt, cone-shaped needle is attached to the lower part of the box, designed to pierce the film of the container holding the liquid to be extracted. A tube connects the needle to the pump. At the push of a button, the electrically controlled pump creates a vacuum and draws the liquid into a chamber inside the box. The lower end of the measuring probe, which measures the pH value, is inserted into this chamber.

3.4. Container for catching the jellyfish

To capture the jellyfish, a container was designed that can be opened and closed at both the top and bottom using lids. Each lid has a rack mounted on it, allowing the lid to be moved back and forth along its guide by means of a gear. This gear is mounted on a shaft located above the lid. The shaft is rotatably mounted with two ball bearings on either side of the container. A groove is integrated into the top of the container to hold a sealing ring, which prevents water from leaking out of the container. Further illustrated in Figure 2:

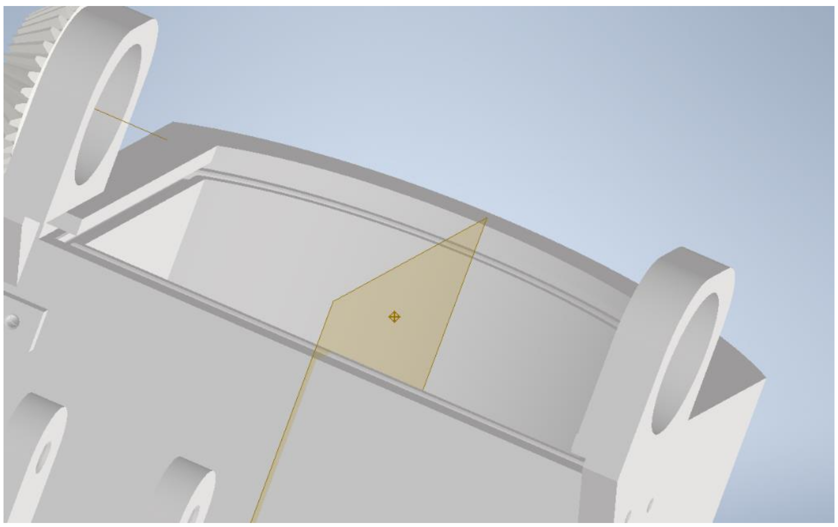

Figure 2: Top of the Container with the Guide Mechanism.

The mechanism for opening and closing the container is driven by a servo motor, which drives a shaft via a gear. This shaft is also rotatably mounted with ball bearings on the top and bottom sides of the container. Bevel gears at both ends of the shaft redirect the rotational movement by 90°. The servo motor is capable of rotating more than 180°. By selecting appropriate gear sizes, the lids can be moved far enough to fully open or close the container.

The same waterproof housing used for the arm drive is used for the servo motor. The container can be mounted to the bracket at the front end of the arm. Since the container and the water sampling device can be easily detached from the arm by removing a single pin, they can be quickly replaced. The Servomotor can also be easily unplugged.

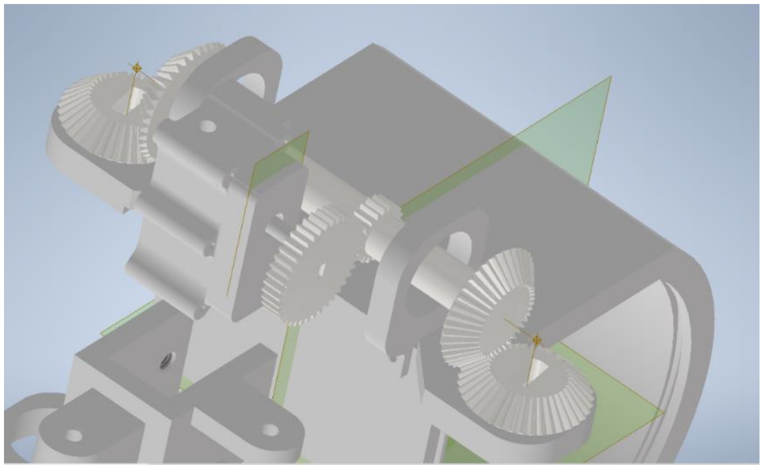

Figure 3: Illustration of the gear's arrangement highlighting the lid mechanism.

4. Electrical Subsystem

4.1. Power Distribution

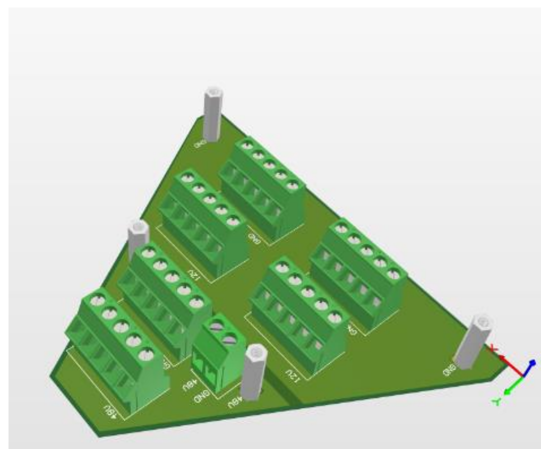

Figure 4: 3D-Rendering of the PDU.

The power distribution system of our ROV is shaped by our unique triangular frame design. This constraint influenced the decision to **purchase external DC/DC converters** rather than developing custom power modules. These converters deliver **12 V at up to 40 A** and include integrated safety features, ensuring reliable power delivery and protection during operation.

Instead of designing a complex internal converter system, we focused on developing a **custom Power Distribution Unit (PDU) PCB**. Its role is to route the 12 V supply from the converters to the ESCs and to pass **48 V directly to the motor controller PCB** via the conductive standoffs. This dual-layered voltage management simplifies wiring, enhances modularity, and supports the sandwich structure of our electronics.

The **3D model of the PDU**, shown in Figure 4, illustrates the optimized connector layout and compact structure that fits cleanly within the ROV's geometry.

4.2. Motor Controllers & ESCs

To control the **BlueRobotics T200 thrusters**, we opted to use **commercially available ESCs** provided by BlueRobotics. Developing our own ESCs was deemed inefficient due to the high-quality performance and robust reliability of the existing solutions.

The control logic is handled by a **Raspberry Pi Pico**, chosen for its low power consumption, compact form factor, high amount of PWM channels and compatibility with I2C and UART for Sensors and Communication. We designed a dedicated **Control PCB** for the Motors, which integrates signal routing, logic-level control, and power regulation.

- The **control signals** from the Pi Pico are routed via JST connectors directly to each ESC.
- A **DC/DC converter** on the same PCB steps down power for the Pi Pico and sensors, supplying **up to 1 A**, which is sufficient for all onboard low-voltage components.
- The layout ensures short signal paths and minimized EMI from the high-current ESC wiring.

The **3D render of the Control PCB**, shown in Figure 5, highlights the integrated sensor section and efficient space usage for connectors and regulators.

Figure 5: 3D-Rendering of the Control PCB.

4.3. Sensors

All onboard sensors are **integrated directly into the Control PCB**, which helps minimize cabling, improves reliability, and allows synchronized sampling. The main sensors in use are:

- **LSM6DSM (STM)** – a 3-axis accelerometer and gyroscope, selected for its compact size, reliability, and strong performance in underwater motion tracking.

- **HMC5883L** – a 3-axis magnetometer, chosen due to its proven accuracy and compatibility with 3.3 V I²C systems.

- Additional **GPIO headers**, 3.3 V and GND rails are broken out for potential future expansions or secondary sensors.

All sensors are connected to the **I²C bus** of the Raspberry Pi Pico, allowing synchronized sensor fusion and time-aligned data collection within the control loop. The integration into the main PCB significantly reduces the system's complexity and supports the modular philosophy of our design.

4.4. Camera System

Our camera system uses **USB modules** for their simplicity, low cost, and easy integration with the **Raspberry Pi**. Since the cameras are not waterproof, we developed a custom housing using **3D printing**, **laser-cut acrylic**, and **epoxy resin**.

The cable is routed through a sealed opening, ensuring full waterproofing.

We use **three wide-angle cameras** (up to 160° FOV) to achieve near **360° coverage**. Placement was optimized using simulations and real-world testing. One camera is mounted on an **articulated arm**, enabling adjustable views during missions. The others focus on the grippers, allowing precise control.

Figure 6: Deployed Modified USB Cameras with the ROV.

All video feeds are streamed via the **Raspberry Pi** to the operator station for real-time monitoring and control.

4.5. Tool Control Unit

To enable flexible and modular tool integration, we designed a **custom Tool Control Unit (TCU)** combined with a **backplane system**. This allows different tool-specific PCBs to be added or swapped without changing the core architecture of the ROV.

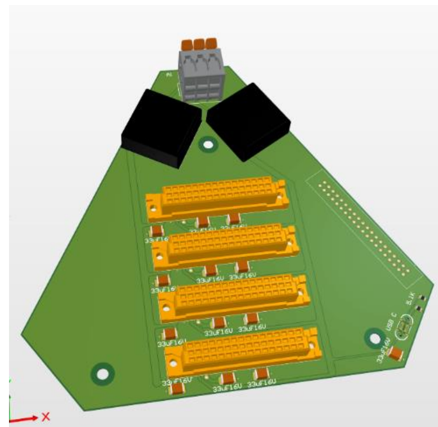

Figure 7: 3D-Rendering of the TCU

The **backplane** features **four standardized slots**, each capable of accepting tool-specific PCBs. All slots are connected to a central TCU, which distributes **power and communication lines** to each module.

The TCU is supplied with **12 V, 48 V, and GND**, and includes onboard **DC/DC converters** to provide:

- **5 V up to 6 A**
- **3.3 V up to 6 A**

These regulated voltages are distributed across the backplane, so that **each slot** receives:

- All **Raspberry Pi GPIO pins**
- **5 V**, **3.3 V**, **12 V**, and **GND**

The **Raspberry Pi 5** is directly connected to the TCU and acts as the central control unit for all tool modules. By passing through its GPIOs to all slots, each tool module has full access to communication interfaces such as **I2C, SPI, UART, and GPIO**, allowing a high degree of flexibility for sensor integration, motor control, or actuation logic.

This modular design provides several key advantages:

- **Hot-swappable development**: tools can be developed and tested independently of the rest of the system.
- **Simplified wiring**: all required signals and voltages are already present on each slot.
- **Future expansion**: the system is prepared for future tools with minimal effort.

The backplane layout is optimized for space and accessibility inside the electronics housing, with robust connectors ensuring safe operation in demanding underwater environments.

4.6. Gripper No.1

Originally, we planned to use an ATMega microcontroller for the Gripper. But due to unexpected **delivery issues**, it could not be manufactured on time.

As a result, we developed a **custom fallback PCB** that retains full compatibility with our **Tool Control Unit (TCU)** and the modular backplane system.

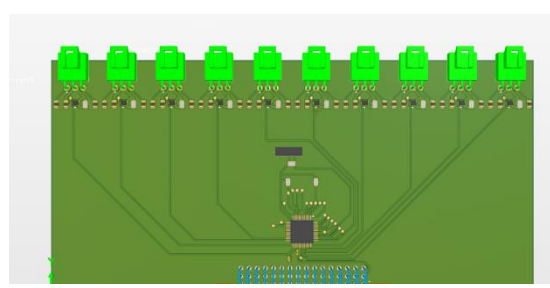

Figure 8: 3D-Rendering of the Hotswap Module containing the ATMega.

The redesigned gripper PCB features an onboard **Raspberry Pi Pico**, which handles local control tasks and communicates with the main system via the shared GPIO interface. The board includes **servo control outputs** connected to modular connectors, allowing servos to be easily plugged in or replaced as needed.

This approach maintains our **modular design philosophy**, enabling tool-specific logic and actuation to be integrated seamlessly without changes to the rest of the ROV system. Despite the setback, the flexibility of our architecture allowed for a reliable and fast recovery, ensuring full gripper functionality for the final integration and testing phase.

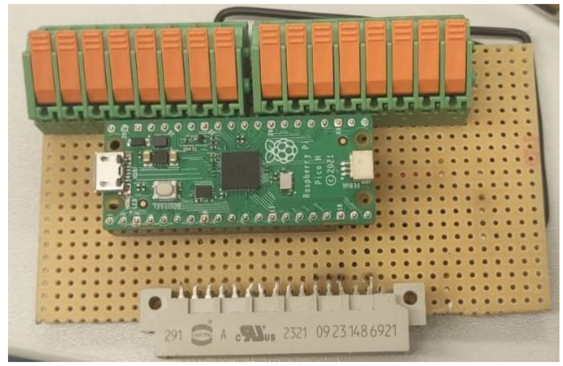

Figure 9: Improvised Hotswap Module based on the Pi Pico.

4.7. Gripper with Pump

On the backplane in the lower box of the ROV, there are slots for circuit boards. These are intended for the necessary electronics for the individual task groups. Power supply (5V and GND) is provided via a connector on the backplane. Additionally, communication with the Raspberry Pi 5 takes place via UART and SPI through the designated pins.

Figure 10 shows the circuit diagram and Figure 11 shows the layout of the PCB, which was designed for controlling the motors, the pH sensor, and the pump.

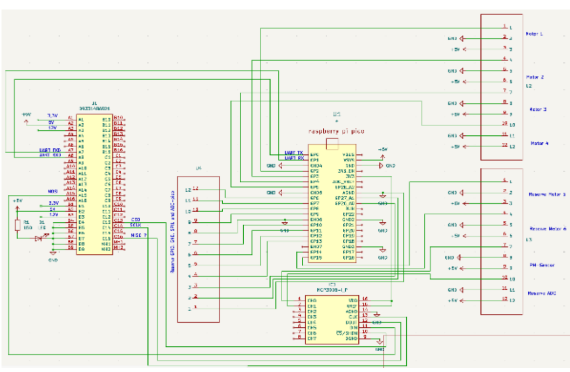

Figure 11: Circuit diagram of the improvised Hotswap-Module.

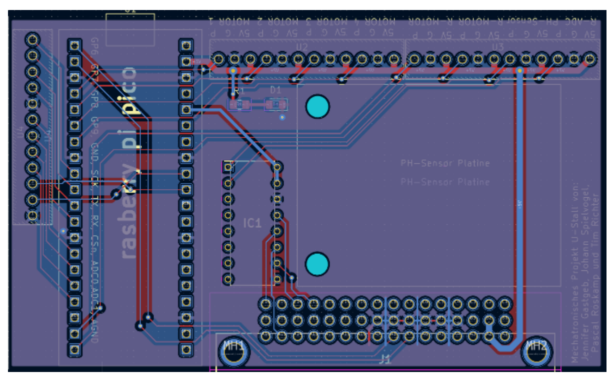

Figure 10: Layout of the Improvised Hotswap-Module.

A Raspberry Pi Pico is mounted on the board to control the motors, and an ADC is used to evaluate the signal from the pH sensor. To transmit signals from the board to the motors, pH sensor, and pump, the board is equipped with three terminal blocks, each with 12 connectors. The terminals are connected via cables to waterproof connectors, through which the motors, pump, and pH sensor are connected.

5. Software

Every complex machine today relies heavily on software, and ROVs are no exception. Our goal of modularity also demands greater effort to ensure proper communication and control for each element of the ROV. While implementing basic control isn't particularly difficult, achieving seamless synergy and ease of operability between all components pushed us to develop a robust and user-friendly software stack for the pilots.

5.1. Architecture Overview

Building upon the modular design philosophy introduced last year, we have further expanded the concept and developed a comprehensive software stack. This architecture enables the independent development and control of the ROV’s two main behaviors: Driving and Interaction.

Each subsystem is aligned with its physical location - Surface PC, Control Box, and Accessory Box -and is responsible for a specific role:

- U.Stall GUI: An all-in-one control interface built using Windows WPF and C#. It handles three types of communication: Gamepad (USB), Control Box (UART), and Accessory Box (Ethernet/MQTT).
- LCE (Master Control Engine): A complex MicroPython-based system. It receives user input from the GUI and manages thruster control, sensor data acquisition, and thrust allocation calculations.
- Motion: A ready-to-use library that streams the USB camera feed. It sends real-time visual feedback from the ROV back to the GUI.
- Task Forwarder: A Python script that listens to MQTT topics containing desired gripper states and forwards them to the appropriate control software.
- Control Software: Lightweight MicroPython scripts for both the simple gripper and gripper with pump. These handle the control of servos according to received instructions.

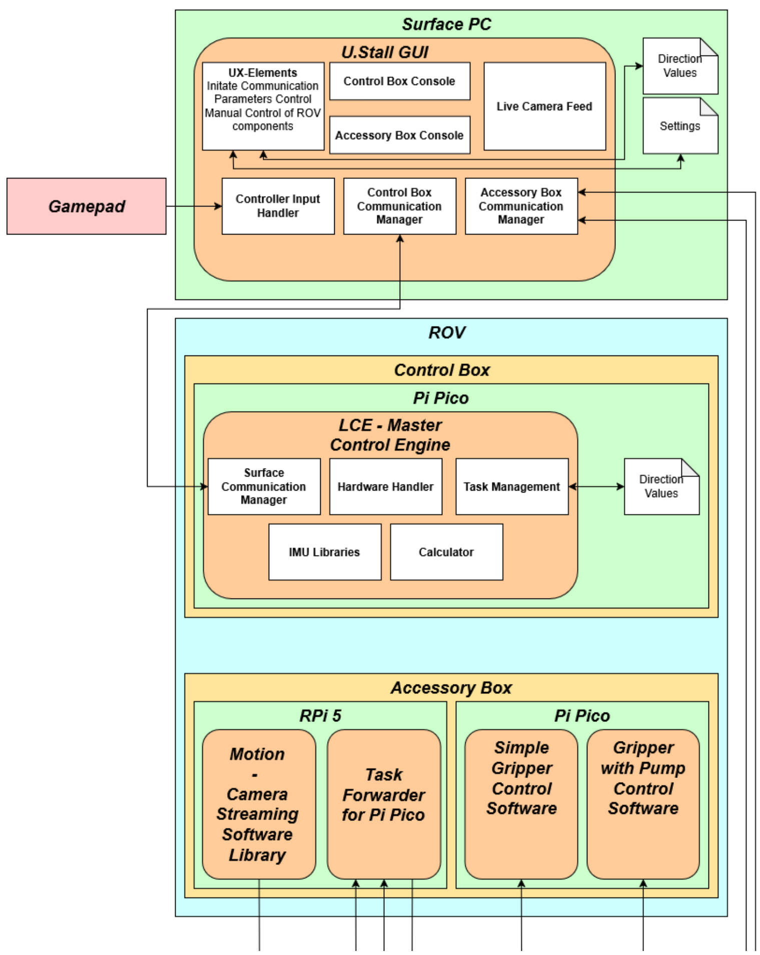

Figure 12: Software Architecture highlighting communication between involved hardware parties in the whole setup.

5.2. Control System

From the Raspberry Pi Foundation recent microcontroller, the “Raspberry Pi Pico” based on the RP2040-Chip, was the to-go choice to develop the Control System on.

IO, ease of development and its cheap price were the heavy factors in deciding to go for it instead of alternatives like the last-year’s STM32 microcontroller.

While C++ would’ve been the better choice for hardware-near programming, the Pico’s relatively high clock speed of 133 Hz and its dual-core architecture is overkill to our requirements. Therefore, deciding to proceed with MicroPython not only made developing the control engine easier, but more accessible for other team members to fix bugs or adjust code on the fly instead of relying on the Main Software Developer.

This also posed an importance on clean and easy to understand code. Therefore, taking inspiration from PLC development in Industrial settings, the code had an easy-to-follow main code (simplified):

```python
# Entry point of the main Program
read_settings_from_memory()
init_sensors()
init_communication()

while True:
    start_time = time.ticks_ms()
    if uart.any():
        data = uart.read()
        if data:
            id = data[0]
            payload = data[1:]

            task_management(id, payload)

    delta_time = time.ticks_diff(time.ticks_ms(), start_time)
    if delta_time < cycle_time:
        time.sleep_ms(cycle_time - delta_time)
```

This structure maintained a set requirement for the desired responsiveness while also discretely defining the tasks required to be executed by the task management module depending on the type of payload to be received.

5.3. Sensor Data Handling

Sensors in control systems have mostly the same defined goal: “Stabilize and assist driving”. A Gyro and Magnetometer provides the necessary instant information needed for active feedback in the form of acceleration and current vehicle orientation. Handling this data further reinforced the key requirements mentioned in the Control System in addition to moving the thrust calculation from the frontend to the microcontroller.

The Pilot gives through the Gamepad his desired DoF, which through a precalculated thrust allocation, results are further then adjusted using the sensor data captured at the beginning of the cycle. The measured time needed between receiving the desired DoF and Thruster reaction is in the 7-8 ms range, which is far below from ours defined acceptable limit of 20ms per cycle.

5.4. User Interface and Communication

This year's frontend achieves what last year’s could not: an all-in-one interface that integrates camera feeds, parallel communication management, and manual component control.

Transitioning from Windows Forms to WPF using the MVVM design pattern significantly improved UI maintainability and the ease of future updates. Although adapting last year’s GUI might have saved time, investing in the new interface has proven worthwhile due to its improved structure and scalability.

Ethernet proved to be a fast and reliable medium for communication between the ROV and Surface PC. To maintain the independence of the two-box system, we utilized the 2 unused pairs (from 4) in a standard Ethernet cable (normally reserved for PoE).

Using a breakout board, we transmitted UART signals from a CP2102 adapter on the PC to the Pi Pico in the Control Box, while preserving standard Ethernet communication for MQTT and Camera streaming for the Accessory Box.

Since UART only requires TX, RX, and GND, and we can use only RX to receive DoF inputs, we could effectively use just 6 out of the 8 Ethernet lanes. This leaves 2 lanes as a backup in case of physical damage to the cable while in a pinch.

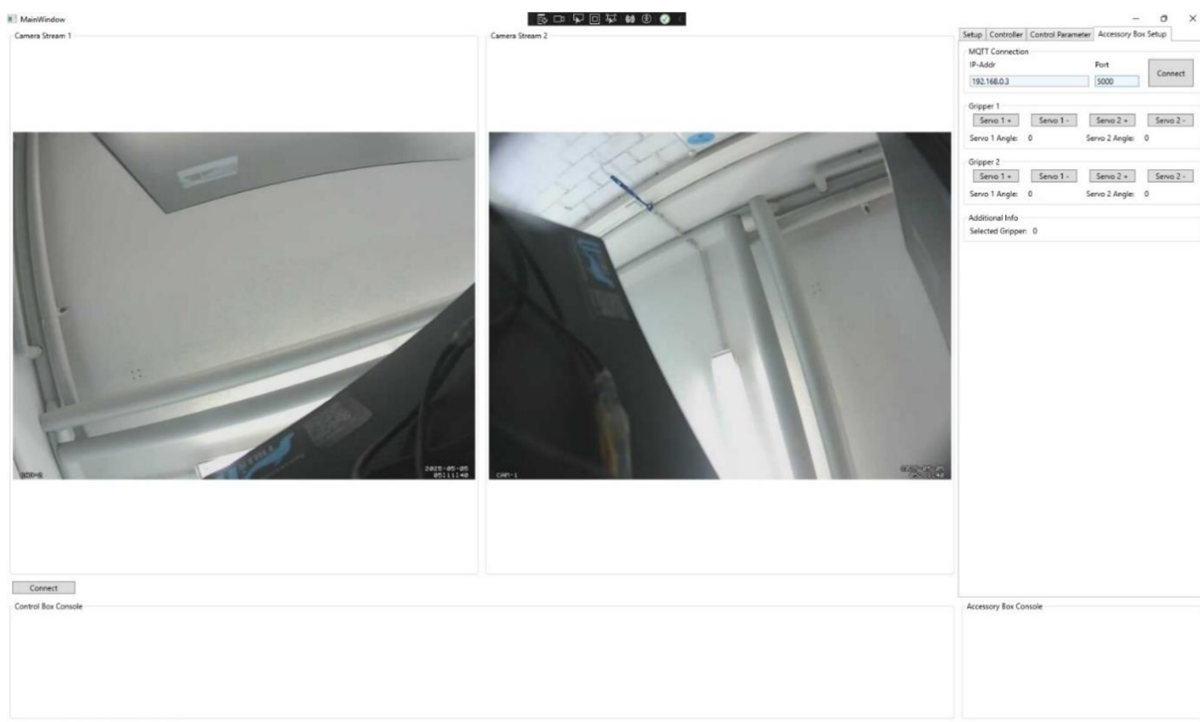

Figure 13: U.Stall GUI incorporating all the necessary forms of control and feedback in a WPF-based application.

5.5. Gripper with Pump

This gripper was developed as a project by a group of students, who later joined the team and worked to integrate it into the ROV.
Initially based on both Python scripts and a web interface, it enabled control of the servos and the pump individually, allowing for the realization of its proof of concept. The web interface also featured live data of the gripper's state and the pH sensor's data, while being hosted on the Raspberry Pi. Upon interaction, the main Python script hosting the website forwarded the data to the Pi Pico, which in turn controlled the actuators and sensors accordingly.

Communication was handled by sending MQTT messages via the web interface, which were then read by the main script running on the Raspberry Pi and subsequently transmitted via UART to the microcontroller responsible for managing the servos, pump, and sensor.

This architecture, as shown in Figure 14, provided an easy way to demonstrate its functionality to interested parties, while also making it easy to integrate into the ROV by implementing a control system in the frontend that sends the necessary values through the same MQTT channel to activate the gripper.

One of the requirements in the given tasks was to develop a pH measurement system. Ours is based on a precise pH sensor, which we calibrated using three different solutions with known pH values. The recorded values serve as the basis for an interpolation, which is implemented in the program and enables reliable determination of any pH value within the measured range. The determined pH values are then displayed in real time either via a user-friendly web interface or the ROV Frontend, allowing for convenient monitoring and analysis.

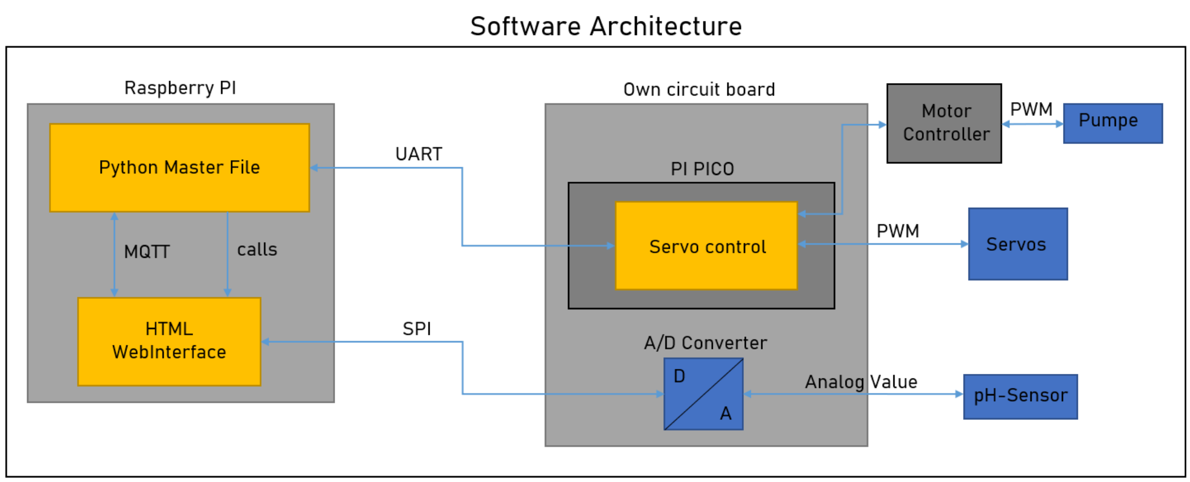

Figure 14: Software architecture of the Gripper with Pump subsystem

6. Project management

U.Stall, the Underwater Robotics Team of Esslingen University, is a passionate group focused on designing and building innovative underwater robots (ROVs). For the 2024-2025 competition, we continue to uphold high standards of organization and project management.

We have implemented a structured approach to ensure clear communication, efficient resource management, and strong team collaboration. Our project management revolves around four key components: team structure, project scheduling, budget management, and tools.

6.1. Team structure

Building on our success from the previous year, we've streamlined the organization of U.Stall, balancing creativity with clear leadership. The team has grown to 11 core members, with departments focusing on Project Coordination, Mechanical, Software & Electronics, and Design & Validation. Leadership is distributed, with specific roles for project management at the departmental level.

Leadership Team: The team is overseen by Felix Harnau, co-founder and team leader, with key mentors Prof. Dürr and Chief Hoover guiding the development process.

Departments and Sub-teams:

Mechanical: Responsible for the mechanical design and assembly of the ROV.

Software & Electronics: Handles control systems, sensors, and onboard software.

Project Coordination: Manages power systems, circuits, and sensor integration.

Design & Validation: Coordinates budget, logistics, and communication.

Each department has sub-leads for critical subsystems, ensuring ownership and expertise development within each project phase.

6.2. Project scheduling

U.Stall follows a structured weekly cycle to ensure the timely completion of tasks and milestones:

Monday Leadership Meeting: A planning session where team goals and updates are set. Each department provides status updates and issues are addressed.

Wednesday Departmental Stand-ups: Smaller team meetings where specific goals are discussed, and obstacles are identified. This fosters collaboration and problem-solving.

Timeline & Milestones: Our project schedule is divided into four main phases, with corresponding deadlines and reviews:

Design Phase: Conceptualizing and modelling the ROV, including design reviews.

Manufacturing Phase: Fabrication and assembly of the ROV, focusing on in-house production.

Testing Phase: Fine-tuning and pool tests to validate the functionality of the ROV.

Final Launch: Preparation for the competition with a comprehensive systems check.

6.3. Budget management

We follow a dynamic budgeting approach. Early in the season, we develop a budget plan that estimates the costs for materials, tools, and team needs. This plan is continuously updated as the project progresses, keeping track of both actual vs. projected costs.

Tracking: All expenditures are recorded in an Excel sheet to maintain transparency and adjust for any unforeseen circumstances. This allows us to make informed decisions about spending, especially when technical challenges arise that may require additional resources.

Lessons from Previous Years: In 2024, we implemented more frequent budget reviews and improved communication within the team about cost-effective decision-making.

6.4. Project management tools

To ensure effective communication and project tracking, U.Stall utilizes a variety of tools:

Discord: For real-time communication across teams.

GitHub: For version control and collaboration on software development.

Google Drive: For sharing and collaborating on project documents and files.

Microsoft Excel: For budget tracking and resource management.

Fusion360: CAD

Altium: Electrical PCB design

We have also started using Aras Innovator for CAD file version control, enhancing our team's ability to manage and track engineering changes, similar to Purdue's approach to CAD management.

6.5. Collaboration and Cross-Department Work

U.Stall places a strong emphasis on cross-department collaboration. Team members regularly participate in cross-functional project teams, such as the embedded systems team (combining electronics and software expertise) and the manufacturing group (collaborating between mechatronics and electronics)

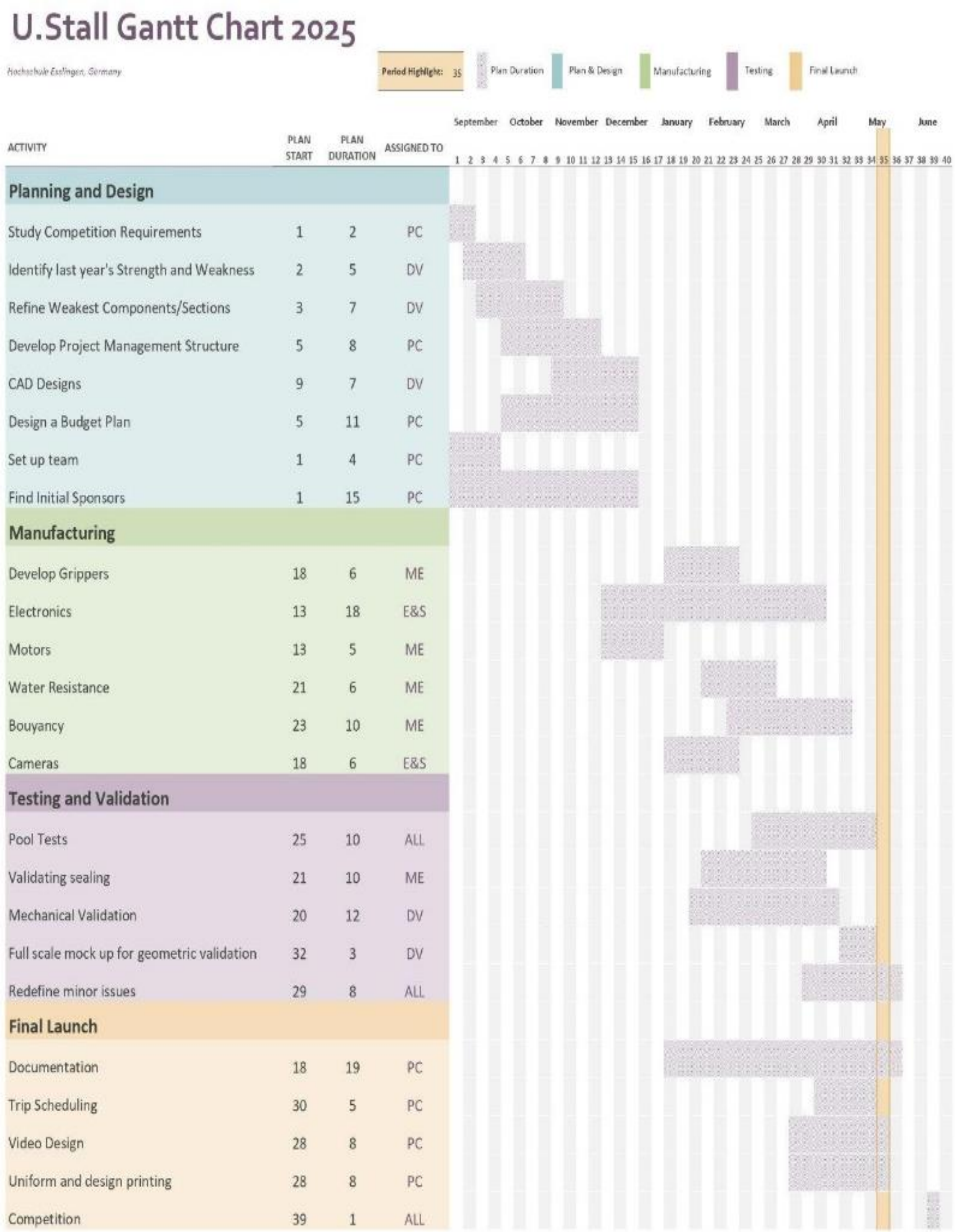

Figure 15: U.Stall Gantt Chart highlighting the time and duration of different phases during development and preparation for the Competition.

Name of Item	Invoice Date	Amount Expended (or Income)	Store Purchased	Category
4TLG. EDELSTAHL PINZETTEN-SET	25/04/2025	-33,11 €	Conrad Electronic	Tools
LÖT KREUZ PINZETTE GEBOGEN + STEUERLEITUNG SW UL-LIYY 8 X AWG 20	25/04/2025	-49,66 €	Conrad Electronic	Electronic
STEUERLEITUNG ÖLFLEX® CLASSIC110 10G0,75	25/04/2025	-31,25 €	Conrad Electronic	Electronic
WIEDERÖFFNUNGSBINDER 150 MM SW 100 ST + Versand + Zuschlag	25/04/2025	-15,54 €	Conrad Electronic	Tools
Square flange receptacle + Plug with cable gland	24/04/2025	-84,61 €	RS Components	Electronic
PCB double-sided, Free Stencil	09/04/2025	-183,44 €	Beta LAYOUT	Electronic
Epoxy Resin + Shipping	08/04/2025	-29,80 €	Filamentworld	Mechanical
GPIO Ribbon Cable, WR-PHD Sockets	08/04/2025	-16,07 €	RS Components	Electronic
Hook & Loop Set (2m x 25mm)	08/04/2025	-4,82 €	Conrad Electronic SE	Tools
Raspberry Pi SC1110	08/04/2025	-64,84 €	BerryBase (via Conrad)	Electronic
Screws + Shipping + Invoice Fee	07/04/2025	-20,40 €	RC-Schrauben	Mechanical
Square flange + plug connector	07/04/2025	-74,54 €	RS Components	Electronic
LSM6DSM adapter board + DC/DC converters	01/04/2025	-60,84 €	Mouser	Electronic
Wiring Extension (0.25mm2)	01/04/2025	-8,43 €	Conrad Electronic SE	Electronic
Wiring, Shrink Tubes, RC Car Bearings	01/04/2025	-81,40 €	Conrad Electronic SE	Electronic
Geschäftsstelle Funding	28/03/2025	3.000,00 €	Geschäftsstelle c/o HE VDF (Ve	Funding
Monocoque case and lid (custom part)	27/03/2025	-2.189,60 €	3D-Form Winterbach	Mechanical
DC/DC Converter TRACO THN 20-4811	24/03/2025	-42,27 €	Mouser	Electronic
Cutter, IMUs, Sensors, Connectors, Capacitors	20/03/2025	-101,57 €	Mouser	Electronic
WAGO Terminal + Shipping	18/03/2025	-8,50 €	Reichelt Elektronik	Electronic
	17/03/2025	-101,17 €	Mouser Electronics Inc.(FR)	Uncategorized
PCB double-sided, Free Stencil (March)	14/03/2025	-260,67 €	Beta LAYOUT	Electronic
	12/03/2025	-138,17 €		Uncategorized
-	28/02/2025	-206,35 €	Mouser Electronics Inc.(FR)	Uncategorized
Reconciliation VAT on acquisition 19.00% Accounting 1442 54792 619 0	28/02/2025	-39,21 €	-	Uncategorized
	28/02/2025	-206,35 €	Mouser Electronics Inc.(FR)	
-	27/02/2025	-65,03 €	Contorion GmbH	Uncategorized
	27/02/2025	-93,87 €	Conrad Electronic SE	
	27/02/2025	-592,29 €	RS Components GmbH	
	27/02/2025	-32,94 €	Reichelt Elektronik GmbH	
BB1047872X8	17/02/2025	-46,90 €	Cornelia Stein Ratepay GmbH	Uncategorized
-	12/02/2025	-61,23 €	Landefeld Druckluft u.Hydrauli	Uncategorized
-	10/02/2025	-145,00 €	Mouser Electronics Inc.(FR)	Uncategorized
Reconciliation VAT on acquisition 19.00% Accounting 1442 54792 483 0	10/02/2025	-27,55 €	-	Uncategorized
	10/02/2025	-145,00 €	Mouser Electronics Inc.(FR)	
Funds call 2025	07/02/2025	10.000,00 €	Richard-Gottschalk-Stiftung	Fundings
	06/02/2025	-40,00 €	Billie GmbH HT Connect GmbH &	
	06/02/2025	-61,88 €	Billie GmbH HT Connect GmbH &	
Use of diving tower	03/01/2025	-300,00 €	Tauchsportcenter Esslingen	Testing
Use of diving tower	18/12/2024	-100,00 €	Tauchsportcenter Esslingen	Testing
Last year savings	01/09/2024	5.000,00 €		Funding
Cars US		-2.236,00 €		Logistic/Trip Expense
donation 1		2.000,00 €		Funding
Flights US		-8.591,30 €		Logistic/Trip Expense
Hotel US		-7.086,24 €		Logistic/Trip Expense
Schuler		10.000,00 €		Funding
Trains to Frankfurt		-371,66 €		Logistic/Trip Expense
Total		**5.950,50 €**		

Figure 16: List of U.Stall's financial report during the year.

7. Testing and Validations

7.1. Mechanical Tests

Before the first box was sent to manufacturing, we carefully tested all used geometries.

For seals, a small test box was machined with interchangeable lids, allowing us to test O-Ring geometries, bolt sealing methods and the Souriau UTS electrical connectors.

This box was taken to a 6 m diving tower and lowered to 6 m for 5 minutes with each lid.

Additionally, a full-scale version of each box was 3D-printed to validate all positions of holes, threads and the internal layout. These boxes were later reused to discuss machining with the machinists.

When the boxes arrived, they had all necessary seals installed and tested at 6 m without any electronics present.

Over the months more parts arrived, they were installed on the ROV to isolate their effect on the vehicle's behavior.

As an example, during the 3rd dive, which was the first test with both the Navigation and Tool Modules integrated, it was discovered that the vehicle was rather unstable during traversal. Through attaching and removing dummy weights and temporary buoyancy elements a working setup of weights and buoyancy elements was discovered and is still in use.

7.2. Electrical Safety Tests

To ensure the safe and reliable operation of our ROV's electrical system, we conducted a series of **Electrical Safety Tests** on all custom-designed PCBs and critical power paths. Given that our system distributes multiple voltage levels 48 **V, 12 V, 5 V, and 3.3 V**—and uses a modular backplane for tool integration, verifying electrical integrity and isolation was essential.

Each custom PCB, including the **Power Distribution Unit (PDU)**, **Tool Control Unit (TCU)**, **Motor Controller Board**, and **Gripper Modules**, underwent the following test procedures:

- **Continuity Testing:** All power lines and ground paths were verified with a multimeter to ensure proper routing and no open connections, especially across the backplane slots.
- **Short-Circuit Testing:** Before applying power, resistance checks were performed between all voltage rails and ground to identify possible shorts.
- **Voltage Regulation Verification:** With power applied, we measured the output voltages of all onboard DC/DC converters to confirm correct operation under both no-load and load conditions.
- **Current Load Testing:** Key converters on the TCU and Motor Controller Board were tested with active loads to ensure they could supply their rated current (up to 6 A) without overheating or voltage drops.
- **Signal Integrity Checks:** Oscilloscope measurements were taken on PWM and I^2C lines to verify clean switching behavior and absence of excessive ripple or noise—especially critical due to proximity to high-current ESCs.
- **Modular Slot Isolation:** Each tool slot on the backplane was tested individually to ensure that a fault in one slot (e.g., overcurrent or disconnect) would not affect adjacent slots or damage the Pi or TCU.

In addition, we tested **fail-safe behavior** by simulating power loss on individual lines (e.g., cutting 12 V or 5 V input), ensuring that the system does not enter undefined states or damage components.

These systematic electrical safety checks were essential for ensuring the **robustness and serviceability** of the ROV during pool tests and mission tasks. Our modular electrical design made fault isolation and component-level validation significantly easier and safer.

7.3. Pool and Field Tests

Our ROV underwent several **pools and field-testing sessions** to validate its full system performance under realistic conditions. These tests focused on verifying **thruster control**, **tool operation**, **buoyancy balance**, **camera visibility**, and **system robustness** under extended operation.

Initial pool tests were carried out in a controlled indoor environment, where all core functions—including movement in six degrees of freedom, gripper actuation, and live camera streaming—were validated. The **thruster behavior** was finely tuned during these sessions to achieve stable hovering and precise maneuverability. In addition, the **communication link** between the surface workstation and the onboard control units was tested for latency and signal reliability.

During one of the later field trials, we encountered a **critical failure**: a **connector on the top electronics box was accidentally stressed during assembly and broke underwater**, leading to **water ingress** and the partial **flooding of the upper electronics compartment**. This resulted in a temporary system failure and required full disassembly and drying of the electronics.

This incident prompted several improvements:

- Reinforcement of all **critical connectors** with mechanical strain relief and adhesive.
- Re-evaluation of **cable routing** and **entry points**.
- Additional pressure and sealing tests before each deployment.

Despite this setback, the modularity of our system allowed us to isolate the damage and restore most functionality quickly. The experience also highlighted the importance of **mechanical reliability** in underwater connectors and guided our design adjustments for future missions.

Subsequent tests confirmed the effectiveness of the improvements, with the ROV performing multiple fully functional dives without further leaks or failures.

7.4. Software Simulations / Dry Tests

Last year's simulation helped test thruster arrangement concepts. However, due to limited manpower, we couldn’t continue its development.

Instead, we used MATLAB to compute thrust allocation values for each DoF. This allowed us to skip trial-and-error testing in water. Dry tests were conducted to verify correct thruster assignment between hardware and software. These tests also validated the reliability of our novel UART-over-Ethernet communication setup in early development stages.

8. Lessons Learned & Future Improvements

8.1. Technical Challenges

Throughout the development of our ROV, we encountered several **technical challenges** that significantly influenced our design decisions and iterative improvements.

One major difficulty was identifying **reliable waterproof connectors** for our modular system. After evaluating various solutions, we chose to use **Souriau connectors** due to their compact form factor, watertight sealing, and proven underwater performance. However, even these high-quality connectors presented limitations: during a field test, **one Souriau connector physically broke** due to lateral mechanical stress, leading to a flooded compartment. This experience highlighted the importance of robust connector mounting and mechanical protection.

Another challenge was the **manufacturing of the upper electronics box**, which—due to internal layout constraints—**could not be fabricated as a single housing**. Instead, it had to be assembled from multiple parts with careful sealing between compartments. This added complexity to both the manufacturing and waterproofing process and required additional validation during integration.

Designing the **gripper system** to handle a wide variety of object shapes and sizes was also demanding. Creating a tool that balances precision, strength, and reach in underwater conditions involves several design iterations. Mechanical tolerances, waterproof servo mounting, and alignment during actuation all needed extensive testing and adjustment.

Additionally, we faced **supply chain issues** during production, most notably, **delivery delays of our custom gripper control PCB**. These delays forced us to implement a backup solution and adjust our development timeline accordingly.

Despite these challenges, we were able to adapt and improve our system, often benefiting from our modular architecture, which allowed isolated development and flexible reconfiguration of subsystems.

8.2. Organizational Challenges

In addition to the technical aspects, the development of our ROV also brought several **organizational challenges**, especially in terms of **team continuity**, **resource availability**, and **time management**.

One of the most critical difficulties this season was the **loss of team experience**. From last year's competition team, only **two active members remained**, which meant that much of the know-how had to be **relearned, re-documented, and restructured**. Onboarding new members and bringing them up to speed required significant effort. The few returning members carried the responsibility of training, technical guidance, and documentation while also leading new development work. This situation highlighted the importance of sustainable **knowledge transfer**, which we addressed by improving internal documentation and establishing modular design principles for easier future handover.

Another major challenge was finding **suitable pool facilities for underwater testing**. As our university does not have direct access to a dedicated testing tank, we had to reach out to local swimming facilities or wait for available time slots in nearby institutions. This **limited the number of full integration tests** we were able to conduct and puts more pressure on getting the system working correctly during shorter timeframes. In response, we made use of **dry testing**, simulations, and modular subsystem validation to compensate for limited in-water test time.

Balancing university coursework, part-time jobs, and ROV development was another challenge for many team members. This required careful **project scheduling**, weekly progress tracking, and strong internal communication to stay aligned. Our leadership structure with **department-level responsibility** and weekly stand-up meetings helped us distribute workload and maintain momentum even during exam periods.

Despite these hurdles, the team remained motivated and grew stronger in collaboration and commitment over time. The organizational difficulties also encouraged us to **professionalize our workflows**, improve documentation culture, and make the project more scalable for future teams.

8.3. Improvements for Next Year

Based on our technical experiences and operational feedback from this season, we have identified several **concrete improvements** that can significantly enhance the performance, reliability, and maintainability of the ROV in future iterations.

1. Redesigned Electronics Box with Optimized Geometry
The current top electronics box was limited in space and caused challenges with internal cable routing, cooling, and waterproofing. For future versions, we plan to redesign the housing to be **wider rather than taller**. This change will help to **lower the center of gravity**, improving stability underwater, while also creating **more space for components** and easier access during maintenance.

2. Additive Manufacturing with Metal 3D Printing
With access to a **metal 3D printer**, we intend to manufacture structural components of the electronics box and other load-bearing parts from **durable, corrosion-resistant materials**. This will increase the mechanical robustness, reduce part count, and potentially allow for integrated sealing features in a single printed component.

3. Improved Buoyancy System
The current buoyancy elements were functional but not optimized in shape and placement. For the next version, we aim to **redesign the buoyancy layout** to better match the ROV's weight distribution and to improve hydrodynamics. A more integrated and streamlined buoyancy solution could also contribute to better maneuverability and reduce drag.

4. Advanced Control System with Feedback Loops
While the current thruster control system is functional, it operates largely in open-loop control. To improve precision and handling, we plan to implement **closed-loop control algorithms** using the onboard IMU data, including **PID-based stabilization** for roll, pitch, and yaw. This would significantly enhance control in more complex mission environments or in the presence of currents.

5. Tool Modularity and Quick-Swap Mounting
We also plan to further develop the **modular interface for tools**, including standardized mounting brackets and signal definitions to allow tools to be swapped quickly during missions or development—without the need for rewiring or reconfiguration.

By implementing these improvements, we aim to build a more robust, precise, and maintainable ROV platform that can serve not only the next competition cycle, but also future student teams as a reliable foundation for advanced developments.

9. Safety Philosophy and Checklist

At U.Stall, safety is more than just a checklist, it's a core part of our team culture. We believe that **technical excellence is only meaningful when paired with responsible, safe practices**, both in the lab and during field operations. As such, safety has been embedded into our workflow from the very beginning of the project.

Our **safety philosophy** is based on the principles of **shared responsibility**, **preventive awareness**, and **continuous improvement**. Each team member is expected to take initiative in identifying potential hazards, communicating risks, and enforcing safe behavior during all phases of the ROV's design and testing.

The modular nature of our system—with high-power components, waterproof electronics, and mechanical actuators—demands particular care when handling, assembling, and deploying the ROV. By maintaining a structured approach to preparation, we reduce the chance of unexpected failure or injury.

To support this philosophy, we created a **Safety Checklist** that must be reviewed before every deployment. It includes:

- **Personal Protective Equipment (PPE):** Closed shoes, tied-back hair, no jewelry, and eye protection where applicable.
- **Workspace Readiness:** Clean, dry tables; secured tether routing; no loose hardware; dry hands during electrical work.
- **ROV Inspection:** Visual check of seals, connectors, power lines, and moving parts before powering on.
- **Operational Protocols:** Verbal warnings before applying power, two-person supervision, and using proper grip points for handling.

This checklist, along with our **Job Safety and Environmental Analysis (JSEA)**, forms the backbone of our commitment to **working safely while pushing technical boundaries**.

10. Acknowledgements

At this point, we would like to express our sincere gratitude to everyone who supported us throughout this project. Special thanks go to **MATE**, **MATE II**, and the **Marine Technology Society (MTS)** for organizing and sponsoring the MATE ROV Competition, which continues to provide young engineers like us with a challenging and inspiring platform for innovation.

Our deepest appreciation goes to our mentors, **Thomas Hoover** and **Prof. Dr. rer. pol. Oliver Dürr**, who guided us through the project with constructive feedback, valuable insights, and unwavering encouragement.

We especially want to highlight the support of our **main sponsor**, **Schuler Andritz**, who not only provided generous financial assistance but also actively promoted our project through **social media collaboration** and outreach. Their partnership significantly increased the visibility and professionalism of our team.

We would also like to thank the **Verein der Freunde der Hochschule Esslingen e.V.** for their reliable backing, as well as **Esslingen University of Applied Sciences** itself for providing us with workshops, lab spaces, materials, and an environment where this project could thrive.

We extend our thanks to **Traco Power**, the **Richard-Gottschalk-Stiftung** and the **Hans und Klara Rösler Stiftung** for their generous contributions to our student research and technical development.

We are also very grateful to the **pool operators** who allowed us to use their facilities and ensured safe testing environments:
Cityworks Göppingen, and **Community of Jebenhausen**. Without their cooperation, proper underwater testing would not have been possible.