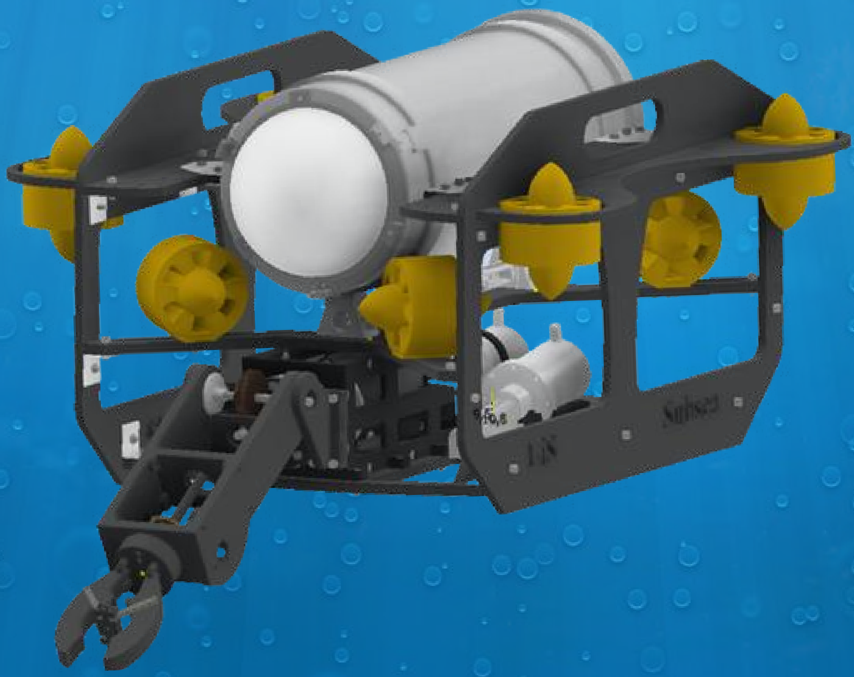
YME



MATE ROV COMPETITION 2023

Technical Documentation

University of Stavanger

Stavanger, Norway

Universitetet i Stavanger

Abstract

UiS Subsea is an organization based in Norway with development of subsea vessels as its main focus. The organization was founded in 2013 under the University of Stavanger, and has its main purpose to motivate students into the subsea field, by creating an innovative and independent working environment. By working closely to the subsea industry located in and around Stavanger, the students are being well prepared to face real world challenges they may face when finishing their studies.

The organisation has participated in the MATE ROV Competition on five previous occasions, first in 2015 and most recently in 2022. During these years, the organization has engaged students writing their bachelor thesis, and challenged them to build an ROV in this time period. Using the knowledge and experiences acquired over the years of studying, this years team has developed a new ROV with the main intent of creating a vessel which is both modular and environmentally friendly. The vessel is modular with further development in mind, to increase engagement from students in earlier part of their bachelor programs, and students from other fields of study.

To realize the goals of a modular and environmentally friendly ROV, the vessel is designed with the possibility of interchangable PCB's in the electrical housing. The ROV has a large frame designed with a focus on environmental impact, where multiple new attachments can be implemented. As an example, the manipulator arm is easy to detach and replace with another tool of choice. To support this, the ROV features excess use of connectors, allowing for expansion of external components. The solutions for the overall ROV is described more in depth in this document.

This years team includes 24 students and three former bachelor students. They are divided into nine teams, where the three former bachelor students serves as mentors of the team. The other 24 students make up nine different teams, working on separate tasks to achieve the common goal of designing an ROV and a float for the MATE ROV Competition. The members of UiS Subsea are shown in figure 1.

Figure 1: The UiS Subsea team.

Contents

Mechanical design

In this chapter, the mechanical design of our ROV, Yme, shown in figure 2, is presented.

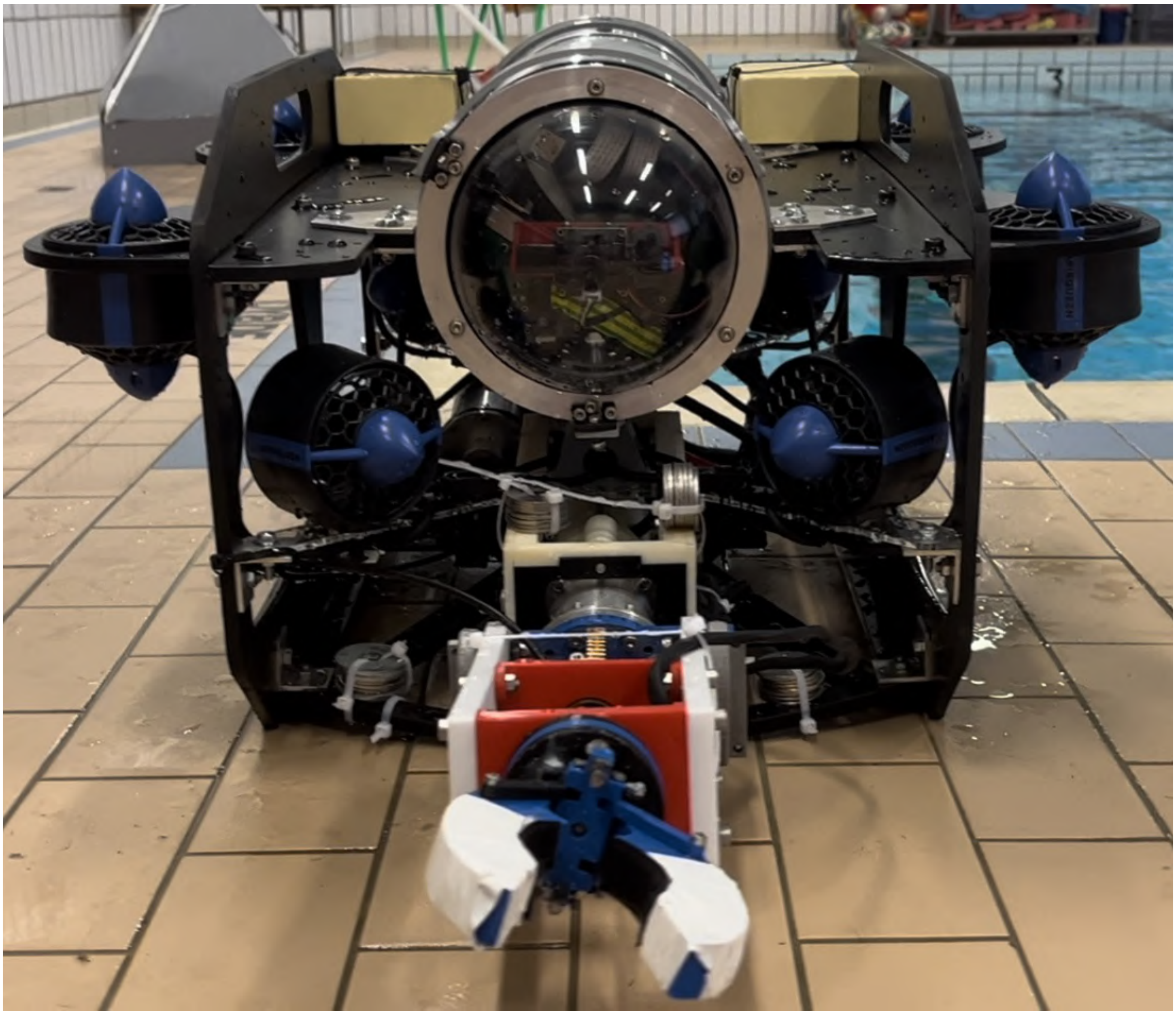


Figure 2: Yme shown from the front.

Frame

The frame was designed using the product development process, with a focus on minimizing environmental impact with material choice, material waste, and energy consumption for production. The goal was to minimize the total environmental impact of the ROV during its life cycle. Additionally, there was a focus on features and properties the ROV should have, including:

- Easy assembly and disassembly
- Minimal maintenance needed
- Low weight
- Natural water stability
- Free water flow through the frame and the thrusters
- Low interference between thrusters

To complete these objectives, several constraints had to be set due to manufacturing limitations with the design and material properties. The frame had to be as lightweight as possible, while still maintaining enough material strength to withstand impacts and forces. With these main aspects to consider, PEHD plates were chosen as the main frame material. This material has good mechanical properties, such as low water absorption, good impact strength, ductility, low density, and corrosion resistance, while being easy to recycle. It also has the benefit of being weldable and could be water jet cut from a local manufacturer. This meant this team could manufacture within the set limitations and adequately address environmental prospects.

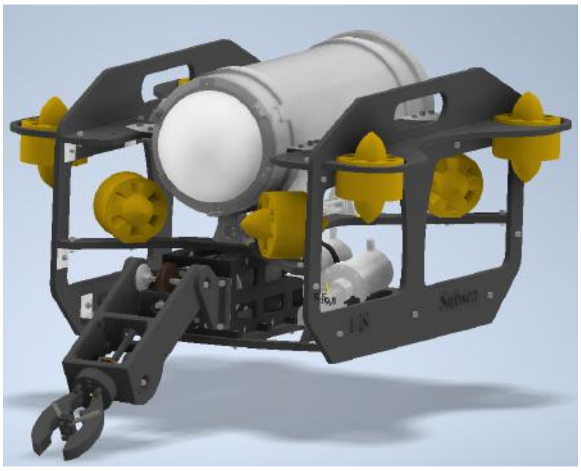


Figure 3: CAD model of the frame.

The frame design is created based on stability and maintenance issues in mind. The total five plates are assembled with custom-angled brackets with nuts and bolts. The two top plates slid into the side plates, ensuring extra rigidity and ample thruster protection. The bottom and top plates have several holes and undisturbed areas where additional gear or altercations can be made. This means that the frame can be reused for future endeavors, thus ensuring a circular economy within the organization. With an open and modular design, the frame allows for free flow and minimized drag. The symmetric design and middle beam ensure sufficient stability from the manipulator and electronic enclosure weight. The water jet production method ensures that no sharp edges on the frame, thus reducing drag and minimizing the risk of injury. Holes for the four vertical thrusters were created in the top plate to protect them against impacts. Furthermore, the electronic enclosure is placed as high as possible, increasing the distance between the center of buoyancy and the center of gravity. This gives the ROV natural stability in the water, thus minimizing power consumption for the regulation system. It slides into the back end of the ROV, making it easy to assemble and disassemble for maintenance. The enclosure is fastened at the front, with three 3D-printed brackets bolted into the flange. These are again fastened to the front band mounting the cylinder to the frame. This prohibits lateral and rotational movements with respect to the rest of the frame, ensuring correct gyro values and regulation parameters. A metal bracket is attached to the ROV frame to prevent the tether connectors from being pulled off the electronic housing, and the tether is secured to the frame by a carabiner hook. The length, width, and height of the ROV are 640x608x360 mm, and the thickness of the plates is 8 mm, except for the bottom which is 10 mm.

Thrusters

Because of their simplicity and ease of implementation, the U8-KV290 thrusters from Apis Queen were selected for the ROV. These can easily be controlled with a PWM signal and comes with a watertight motor controller, type ESC, that is powered at 12 VDC. At 12 VDC the maximum power provided by each thruster is approximately 36 N. This gives powerful and simple to use thrusters that only needs to be fitted with the included thruster guards to comply with the competition manual (MECH-006). Figure 4 shows the front side of a thruster fitted with a thruster guard.

To make an easily controllable ROV, eight thrusters are utilized. Four of these are mounted horizontally with an angle of 45° relative to the frame. These are used to control the horizontal movement of the ROV. The horizontal thrusters are mounted close to the electrical housing in order to minimize tilting under translational motion. In addition, there has been made an effort to place the thrusters such that the center of mass is located in the center of the thruster configuration. This will minimize rotation while moving, and keep the ROV in place while yawing. The other four thrusters are mounted vertically in each corner of the ROV, and are used to control the stability and depth of the ROV. These thrusters are placed with as much spacing between them as possible to obtain an effective stability control. The thruster configuration is shown in figure 5.

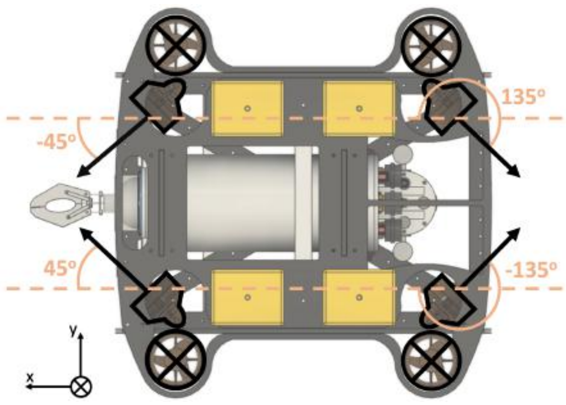


Figure 5: Thruster configuration.

Electronics housing

The electronic enclosure is designed to protect and provide sufficient cooling to the internal components. The housing consists of five main parts: Top cap, end cap, body, flange, and acrylic dome, all displayed in figure 6. All of the parts except the dome are made from aluminum, a material with excellent properties such as thermal conductivity, corrosion resistance, weight reduction, and machinability. The cylindrical shape provides ample surface area and reduces the required wall thickness to withstand pressure up to 100m depth. This makes cooling the electrical components easier, thus minimizing internal pressure build-up risk. Disregarding the connectors, the enclosure is 463.62 mm long and has an outer diameter of 210 mm.

Figure 6: Exploded view of the electronics enclosure.

The front end has a clear acrylic dome in order to provide a window for the front-facing camera. It is sealed with a gasket and a bolted external flange. All of the connectors and plugs are mounted on the end cap, with the three 90° low profile connectors facing downwards. The pressure relief valve ensures that over-pressure is no issue, thus allowing for a bolted connection of the end cap to the main body. The end cap and top cap use Nitrile o-rings to ensure a watertight seal, a material with good compression ratings and durability.

Figure 7: All connectors that are used on the ROV.

Buoyancy

In order to ensure a functioning ROV that is easy to control, neutral buoyancy was required. To achieve this goal, symmetry, and weight optimization were employed for all components. The electronic housing was placed on the same horizontal plane as the vertical thrusters, providing stable movements in the roll direction, shown in figure 8. The righting moment was corrected by ensuring that the Center of Buoyancy and Center of gravity was on the same vertical axis. Due to the negative buoyancy of connectors and other components on the back of the ROV, it tilted upwards. To fix this problem, buoyancy elements were placed at the rear and ballast at the front, thus ensuring stability and proper alignment. Lead is often used as ballast due to its high density but was discarded due to its toxicity which may affect the entire ecosystem. The ballast needed to be corrosion-resistant, durable, and have high density. Stainless steel was therefore chosen as ballast and waste material from the University workshop was used to manufacture these.

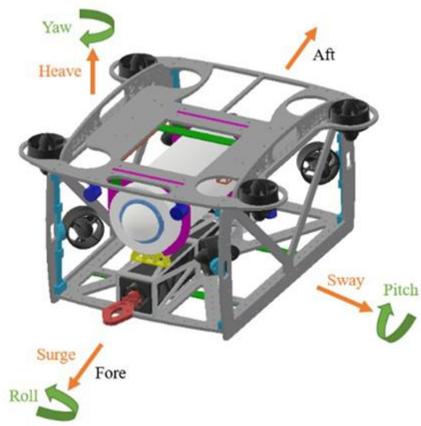


Figure 8: The six degrees of freedom for a ROV.

Manipulator arm

The designed manipulator arm for the ROV includes three degrees of freedom, being rotation, tilt and extrusion. Along with this, it also includes a pitch mechanism. To realise the extrusion, a lead screw is rotated, moving the manipulator arm in and out. The movement is restricted by attaching the arm in an 3D printed cage. To support the arm, support walls with guide arms, shown in figure 9, is used on each side of the arm in the cage.

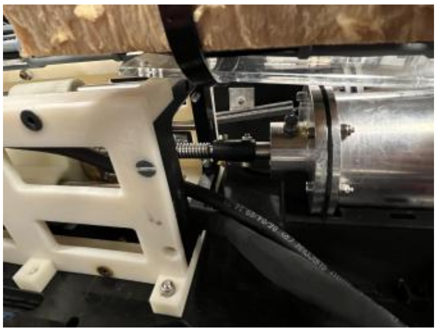


Figure 9: Screw, guides and supportwall for the arm.

To rotate the gripper on the manipulator arm, a worm wheel is mounted to the shaft of the gripper in the outer part of the arm, shown to the left in figure 10. This is rotated by driving the worm gear, mounted on below of the worm wheel, as shown to the right in figure 10. This worm gear is driven by spur gears connected to the BLDC motor. This assembley is mounted in a box, protecting the mechanical parts from comming into contact with objects.

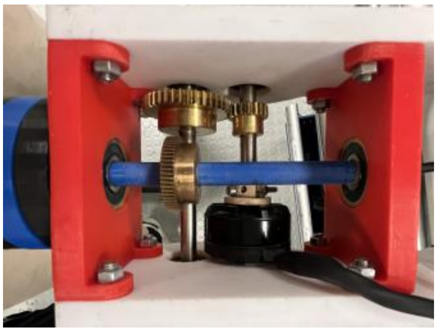


Figure 10: Worm wheel (left) and reduction gear (right) to rotate the gripper.

The pinching mechanism is realized using the principle of bicycle breaks. By using a Bowden cable actuated by a motor. The front piece, shown in figure 11, is compressed, mechanically closing the gripper. The front piece is spring loaded, opening the claw when the force from the Bowden cable is decreased.

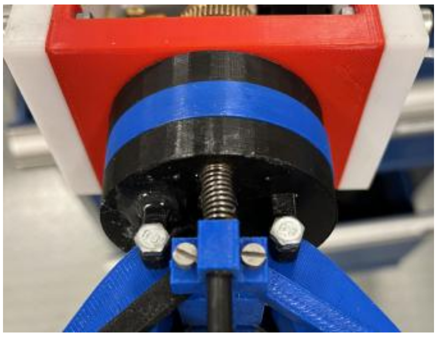


Figure 11: Front piece on the gripper.

The tilting mechanism is realized using a worm and gear coupled with a stepper motor as show in figure 12. This allows for bidirectional tilting of the manipulator arm assembly in the upward and downward directions. The shaft that is coupled with the stepper motor is supported by a ball bearing fitted in the 3D-printed housing for the tilting mechanism. The worm is fitted on the shaft, locked with set screw and rotates the manipulator arm assembly, when the stepper motor turns the shaft coupled to the worm gear.

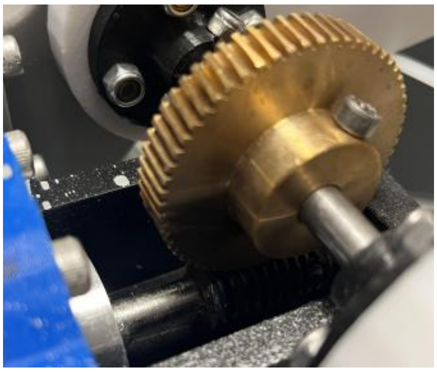


Figure 12: Worm gear, motor and worm wheel on the gripper.

To actuate the manipulator arms, the BLDC motor *Eaglepower 3508 390KV*, shown in figure 13, and the *NEMA17* stepper motor, shown in figure 14, are used for the different degrees of freedom. The *Eaglepower 3508 390KV* motor, typically intended for propellers on flying drones, has also proven to be effective for the manipulator arm on the ROV. The greatest advantage of the motor is that it is lightweight, with a stated weight by the supplier of 88 grams.

Figure 13: Eaglepower 3508 390KV.

The NEMA17 stepper motor was chosen due to its 65 Ncm of holding torque and 55 Ncm of torque at 240RPM. When geared up this provides the torque necessary to move the manipulator arm in the specified degrees of freedom. A stepper motor also gives a very controllable way to move the arm in a controlled fashion. The NEMA 17 motor has 1.8°step but the accuracy can be increased by utilizing half-stepping or micro stepping.

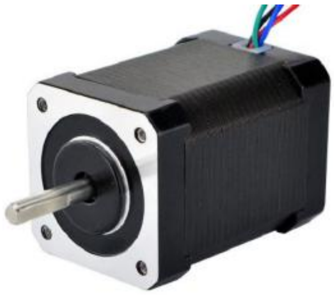


Figure 14: NEMA17 stepper motor.

To meet the requirements of the competition manual (ELEC-018E), the motors' stators are sealed with thermal epoxy. The electrical resistance was measured afterwards with an insulation tester as the procedure, *MATE Technical Bulletin - Sealing Brushless Motors*, suggested. The resistance was measured to be greater than 200 MΩ. The results after the sealing process is shown in figure 15.

Figure 15: Waterproof Eaglepower 3508 390KV.

For the stepper motors to comply with the requirements in the competition manual (ELEC-018E) it was necessary to create three aluminum houses. Each aluminium house consist of a MacArteney micro ciruclar connector mounted to the aluminium house and a flange with a ball bearing and a synthetic grease seal where the stepper motor is mounted on.

Figure 16: Hosuing for NEMA17.

Electrical system

The overall electrical system for the ROV is shown in figure 17. Each part of the system is explained in detail in the subsections that follows.

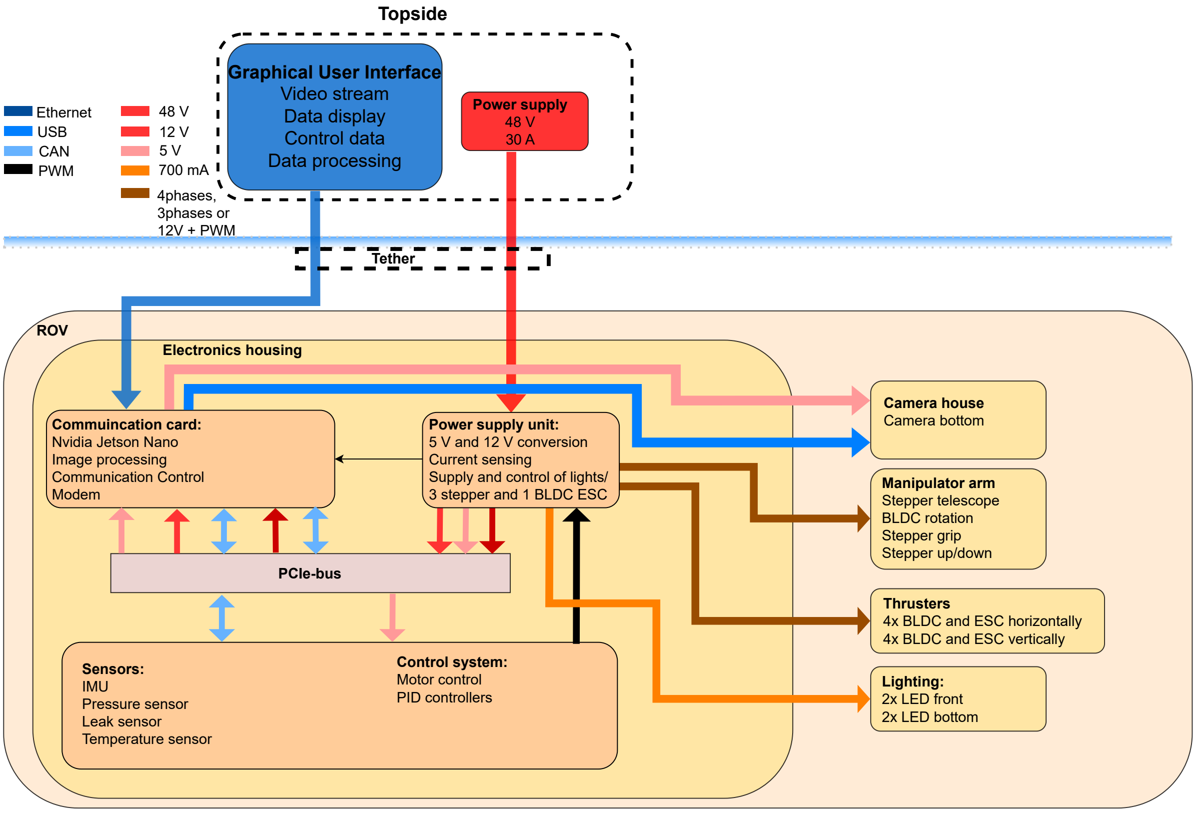


Figure 17: Simplified block diagram of the ROV.

Tether

To supply power and communicate with the ROV, a newley developed teather is used, illustrated in figure 18. It consists of two main parts, being the cables supplying power to the ROV, and cables allowing for communication between the ROV and topside. To supply the ROV with power, stranded 10 AWG cables are used, reducing power loss, along with a flexible cable with minimal effect on the mobility of the ROV. To allow for communication between the ROV and topside, a cat6 ethernet cable is used, so that the there are easier to access spare parts. The tether is filled with cellular plastic to make it neutrally buoyant. The cellular plastic used is low moisture absorbing, flexible and robust, making the overall tether durable.

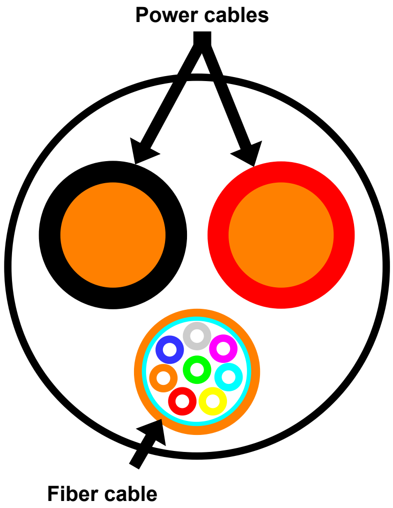


Figure 18: Illustration of the tether used.

Connectors

All power and communication go through connectors, shown in figure 19. These connectors are delivered by *MacArtney Underwater Technologies* and is rated to depths of up to 8000 meters. The connectors are connected to the thrusters, the motors in the manipulator arm and an external camera. The connectors are also used to connect the tether to the electrical housing, supplying power to the ROV, and communication over ethernet. There is also used a penetrator from Blue Robotics to mount a pressure sensor, which is potted with hard epoxy in the penetrator. To release pressure, the backplate includes a pressure relief valve.

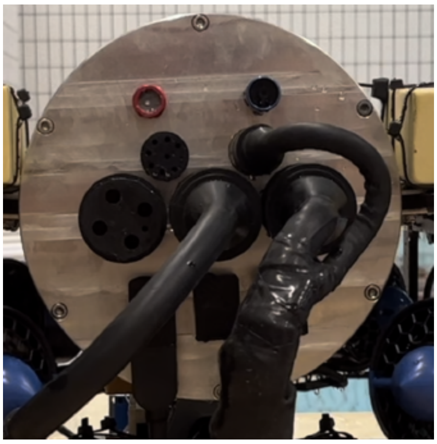


Figure 19: Connectors used to supply power to and data from external electronics.

Cameras

Two sets of cameras and one stereo camera are mounted on the ROV, the stereo camera and one set of the regular camera is facing forward, and the other set facing downwards. The housing containing the downward facing camera as shown in figure 20, while the other cameras are mounted inside the electrical housing. Using synced and calibrated stereo cameras makes it possible to calculate distances to objects, which in turn enables the possibility to calculate objects' widths and heights. Both cameras inside the electrical housing are mounted on a pivot with a servomotor, and can therefore be tilted ± 30° from the GUI to give the pilot access to a larger field of vision. The cameras are connected to a mini-PC mounted inside the electronics housing using USB.

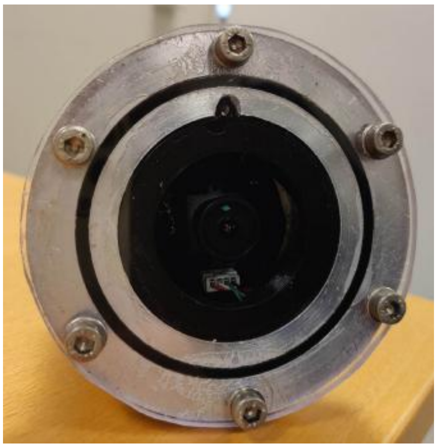


Figure 20: External camera house. Camera type: Waveshare OV2710. Maximum resolution: 1920x1080. Camera sensor: OV2710.

Lighting

On the outside of the ROV, two pairs of external light sources are used. The light sources used are *MKRAWT-H2* LEDs mounted on aluminum PCBs, shown in figure 21. They make a strong light source, able to light up objects at a distance of 1 m from the ROV, with no external non-ROV lighting. This makes the ROV compatible for usage in other situations which does not include external non-ROV light sources, such as operations in sea water. The lighting from the LEDs are controlled using a LED driver, so that optimal lighting of objects can be achieved at different distances. The driver is current-controlled, mitigating instances of thermal runaway.

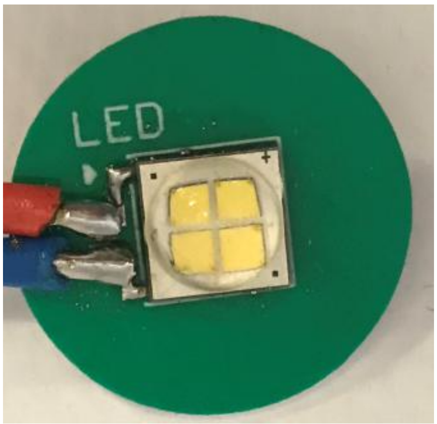


Figure 21: LEDs making the external light sources on the ROV.

Onboard Electronics

Onboard there are a total of four subsystems consisting of the communication and vision system PCB in the front. The next PCB from left to right, is the sensor system, then the next two PCB's are for the control system for thrusters and the manipulator. The last three PCB's are for the power supply system. All systems are separated to its own PCB, reducing electrical interference from the power system to the more delicate sensor and communication systems.

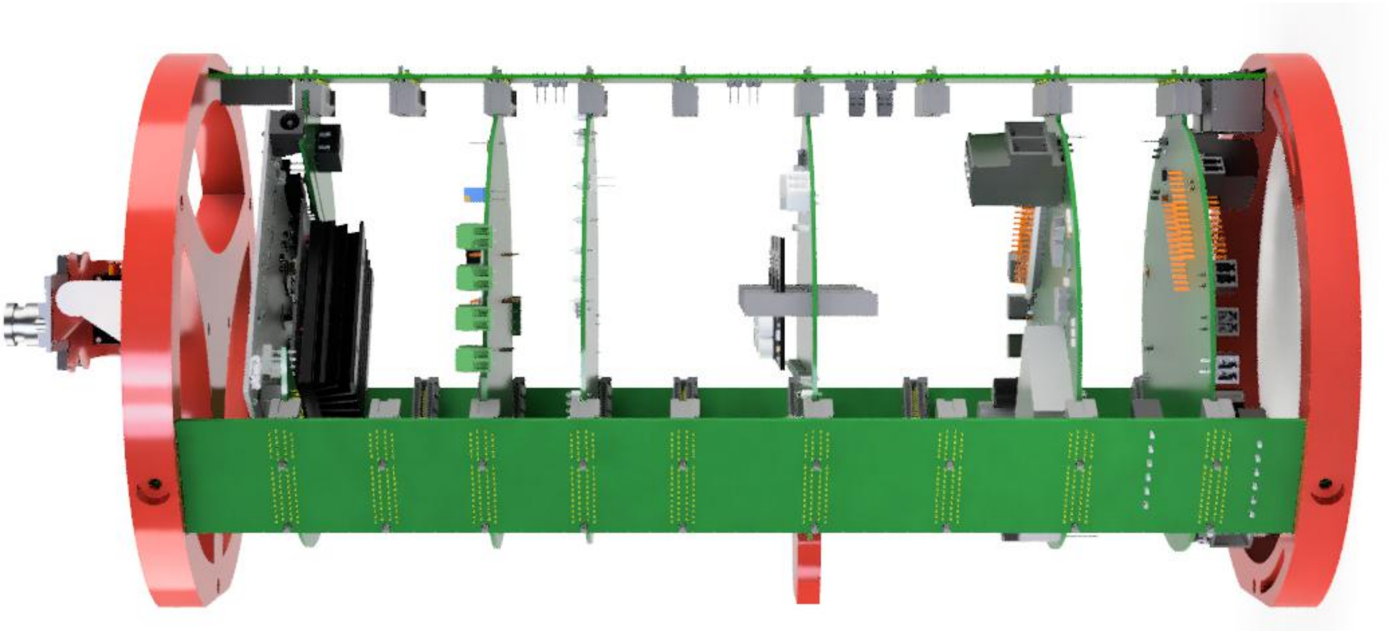


Figure 22: Onboard electronics in the electrical housing.

To mount the different PCBs, three separate circuit boards is used, shown on the right hand side of figure 22. Each PCB is fitted with three PCIe-x4 connectors, which creates a multibus interface between the circuit boards. The PCIe is used to both supply the onboard electronics with power, and forms the communication-bus between the different PCBs. This means that circuit board can easily be swapped and only require to have the same setup on the PCIe contact, making the system on the ROV scalable.

Power supply unit

The power supply unit is designed in-house using off-the-shelf DC/DC-converters to convert the mainline 48 V into the voltages needed on the ROV. The structure of the unit is illustrated in figure 23.

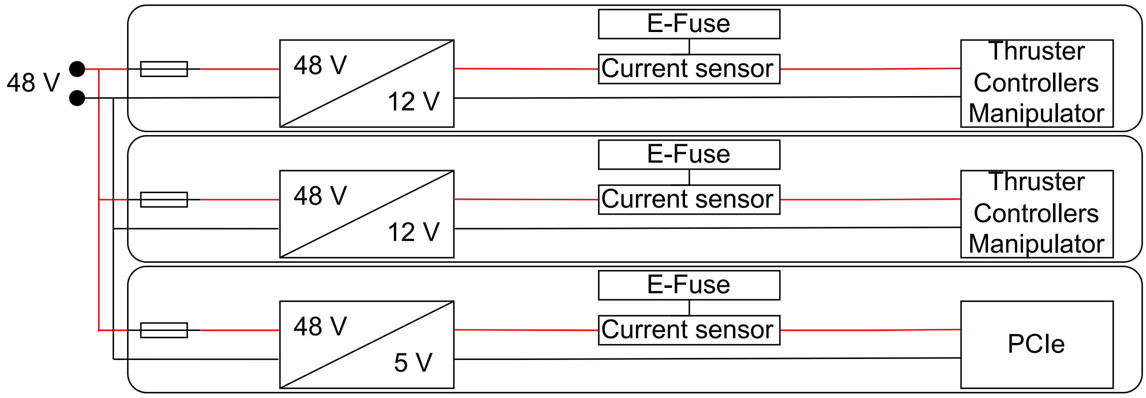


Figure 23: Block diagram of the power supply units.

Power for the thrusters and motors in the manipulator arm is supplied using two separate iddentical PCB's outefitted with a quarter brick 48/12 V DC/DC converter. These converters are chosen due to their high power density and nominal efficiency rating of 97.1 % for the converter supplying the thrusters, and the motors in the manipulator arm. This allows for conversion with minimal power loss and occupied space. Alongside this, due to to the standardised size of the converters, high quality heatsinks are used, allowing for great heat conduction. With the heatsinks, attachment for fans to each converter have been designed, further increasing the heat conduction of each converter.

The other PCB uses a converter to step down 48 V to 5 V, to supply the single-board computer on the ROV, as well as the microcontrollers for the separate subsystems. These are converters with low voltage ripple, to reduce the risk of overvoltage for the most critical electronics in the ROV.

Alongside the converters, the power supply unit includes three current sensors for the circuits with the most variable current draw. This allows for visual inspection of the power consumption on the ROV, whom the data is used to improve the overall system and reduce the sources of error when troubleshooting.

All power supply PCB's are outfitted with a slow fuse on the 48V side and an electronic fuse that is resettable on the 12V side of the converter. This is done to avoid instances where the ROV has be to retrieved from water because a physical circuit break has been triggered, mitigating suspension of operations due to overcurrent. The complete power supply units is shown in figure 24 (note: only one of the 12V pcb is displayed).

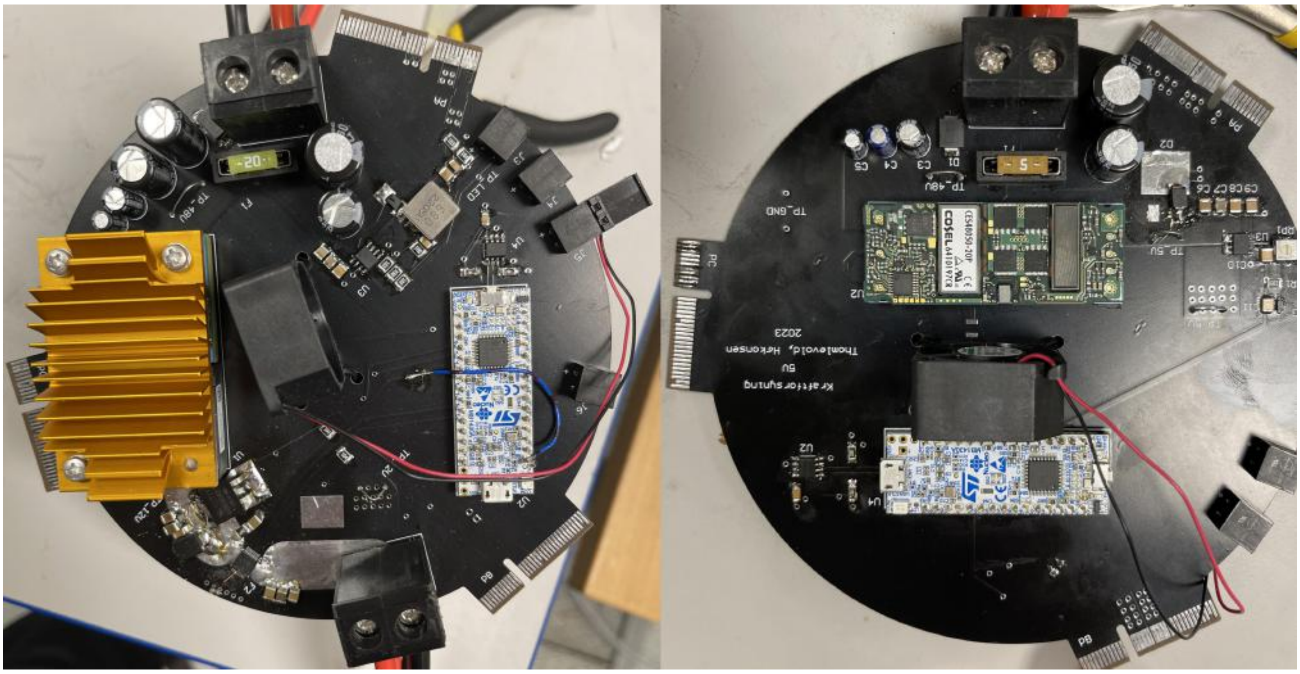


Figure 24: Power supply units PCB.

Communication unit

The communication unit consists of an Nvidia Jetson Nano 4GB development kit, with the bare PCB mounted on a carrier PCB for connection to the PCIe connector and peripheral devices.. Figure 25 shows this carrier board. An SPI-CAN carrierboard is connected to the Jetson and is used to translate the signals coming from topside into CAN bus packages to be distributed over the CAN bus to the other units inside the ROV.

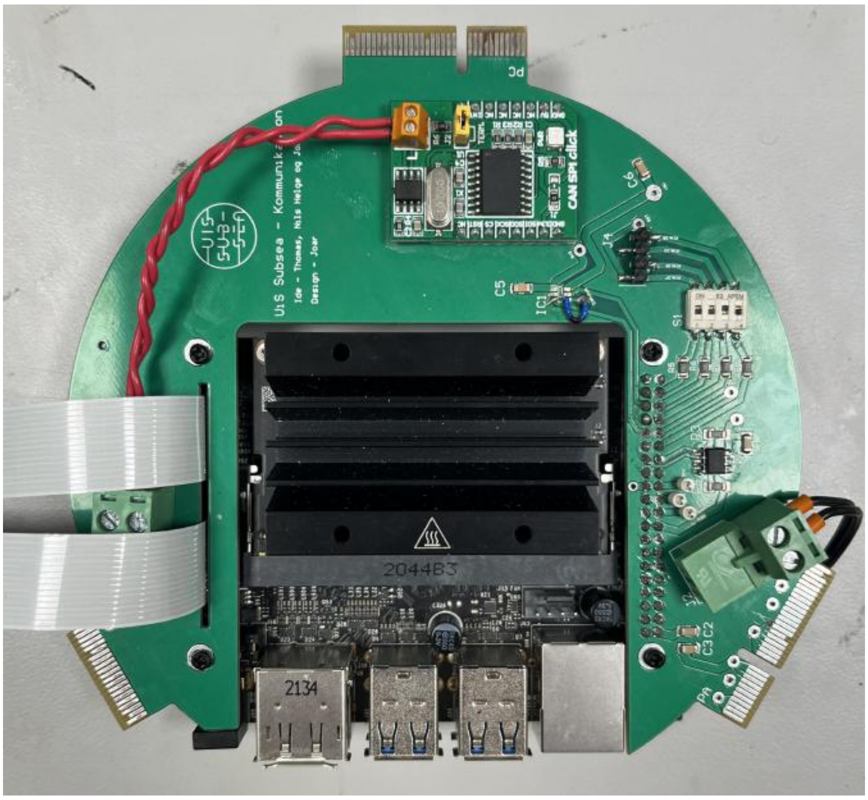


Figure 25: Communication unit PCB.

The video data from the stereo cameras are collected through the MIPI-CSI interface while the video data from the regular cameras are collected through USB. The data is processed using the hardware accelerated encoders and decoders on the Jetson. The communication with the topside systems is done through a cat6 Ethernet cable, the UDP and RTP protocols is used for video transmission and TCP for control and information.

Sensors

The sensor system of the ROV is able to measure depth, roll and pitch angle, temperature and moisture. The sensor system is built in-house with simplicity in mind, where only the most necessary measurements are implemented. With these measurements, orientation of the ROV is easily controlled with PID controllers, and safe operation under water is assured. The sensor system shares space together with the control system, and is located on the top PCB mounted in the electronics housing as shown in figure 22. The complete PCB is shown in figure 26.

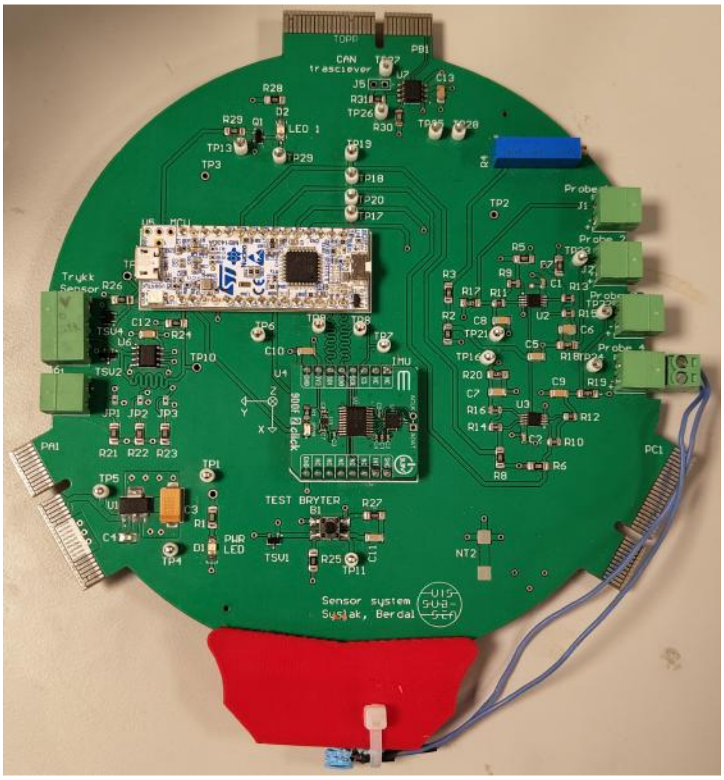


Figure 26: Sensor and control system.

The sensor system is built around the *STMicroelectronics NUCLEO-G431KB*, which is a development board using the *STM32G431KB* microcontroller. The *STM32G431KB* provides quick data processing with an FPU module and CPU capable of operating at a maximum frequency up to 172 MHz, and is able to communicate with the rest of the ROV using its onboard CAN module. The sensor system sends processed data from the four sensor measurements at a frequency of 20 Hz, which are connected to the microcontroller by using the SPI and I2C protocols, as well as direct inputs using the GPIO module.

The sensor system consists exclusively of sensors requiring 3.3 VDC supply voltage. Therefore, an onboard voltage regulator is required, converting the supplied 5 VDC to 3.3 VDC.

Moisture detection is implemented on three different locations in the electronic housing within the ROV and covers the front of the housing where the front stereo camera is located, the back of the housing where the connectors are located, and two in the middle bottom. This provides an overview of where the leakage occurs if the ROV were to leak. The moisture detection system is based on the *Blue Robotics SOS Leak Sensor*, but modified in a way that provides several connection points across the electronics housing.

The sensor system uses a temperature sensors on each of the PCB's to measure temperatures across all systems inside the ROV. The temperature sensor used is the *STMicroelectronics STTS75*, which provides a measurement range of -55°C to 125°C, and an accuracy of ±0.5°C.

Depth measurement is fulfilled by measuring the pressure around the ROV when submerged in water. By first measuring the pressure at surface level when the ROV first gets submerged, depth can be calculated by subtracting the surface water pressure from the current pressure of the water around the ROV when it dives deeper.

The sensor system uses the *TE Connectivity MS5803-07ba* pressure sensor for depth measurement, which has a maximum range of 7 bar and an accuracy of ±75 $mbar$ when submerged in water with a temperature of 20°C.

Roll and pitch angles are calculated using a combination of a gyroscope and an accelerometer implemented on an IMU unit. By combining the precision of the gyroscope and the accuracy of the accelerometer using a complementary filter, measurement of roll and pitch angles are reliable and forms the basis of excellent PID controlling. The IMU unit being used is the *TDK InvenSense ICM-20948*, which includes a gyroscope with a measurement range of ± 250 dps and a sensitivity of 131 LSB/dps, and an accelerometer with a measurement range of ± 2 g and a sensitivity of 16.384 LSB/g.

Control system

The navigation and control system of the ROV use s two PCBs: PCB-NavCon[1] and PCB-ManPu[2]. As the motor controllers for the thrusters are waterproof, there was no need to create a third PCB. Figure 27 displays a side-by-side view of PCB-NavCon on the left and PCB-ManPu on the right, illustrating the differences and distinct features of each.

The navigation and control system of the ROV is divided into two subsystems, manual and automatic, and is implemented on an STM32 NUCLEO-G431RB development board[3]. This development board is mounted on top of PCB-NavCon, shown on the left in figure 27. PCB-NavCon is the third topmost PCB depicted in figure 22.

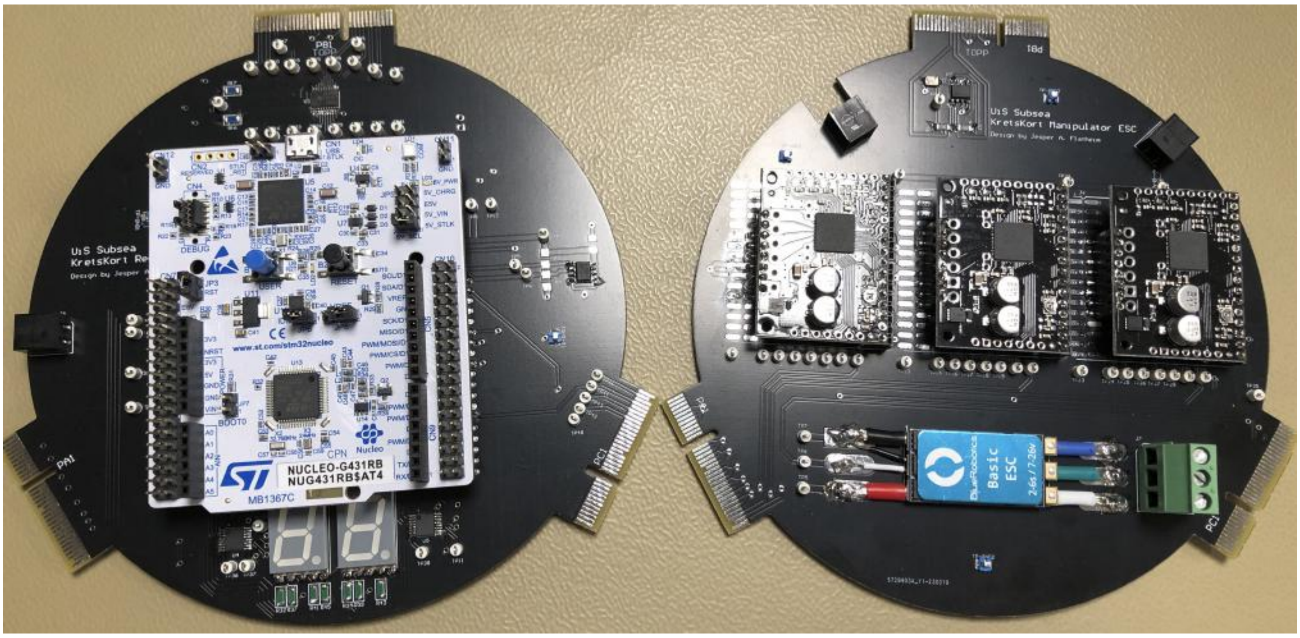


Figure 27: Shows the two PCBs for the control system. The PCBs have the STM32 development board and the stepper motor controller, respectively, mounted to the headers on the PCBs.

PCB-NavCon operates with both 5 V and 3.3 V, and encompasses five circuit areas: the development board, seven-segment display, signal buffer, CAN communication, and temperature sensor. The 5 V supply, delivered through the PCIe-x4, powers the development board circuit, seven-segment display circuit, and the PWM signal buffer circuit. The 3.3 V supply, downregulated on the development board, is utilized by the CAN communication and local temperature sensor circuits.

The development board uses twelve PWM-signals to control all the motors on the ROV, eight for the thrusters and four for the manipulator. All these signals are sent from PCB-NavCon to the PCIe-x4 con-

[1]PCB for navigation and control system
[2]PCB for the motor controllers of the manipulator
[3]With an STM32G431RB microcontroller unit (MCU).

nectors. The thruster PWM-signals are routed into two CAT6 Ethernet connectors, while the manipulator PWM-signals are directed to PCB-ManPu.

The purpose of the seven-segment display circuit, is to provide information that can provide easier debugging when not connected to the rest of the onboard electronics. Using two displays, it's possible to have two digit numbers, and numerous characters.

The signal buffer circuit provides a parallel solution for transmitting PWM signals. This means you can choose to either send the PWM signals directly through the signal lanes to the PCIe-x4 or via the signal buffer. Using a signal buffer protects the development board against potential feedback signals or noise from the PCIe-x4 connectors. Another advantage of using the signal buffer is the ability to select the voltage of the PWM signals within the 2-6V range, instead of the standard 3.3V generated by the MCU on the development board. When selecting voltage via the signal buffer, the voltage load is transferred directly from the PCB power layer to the signal buffer, bypassing the development board. This reduces stress on the development board. Since the PWM-signals for the manipulator travel a short distance, these four signals are not included in the signal buffer circuit and are sent directly to the PCIe-x4.

The CAN communication circuit facilitates software communication with the rest of the onboard electronic system. This communication occurs between the STM32 development board and the PCIe-x4, via the CAN circuit. The temperature sensor monitors the temperature on the PCBs surface to ensure that no components are overheating.

PCB-ManPu houses the motor controllers for the manipulator, along with a temperature sensor.

The motor controllers on PCB-ManPu are divided into two different groups: ESCs [4] and SMCs [5]. There is one ESC for the BLDC motor[6] and three SMCs for the NEMA17 stepper motors. The ESC operates at 12 V, while the SMCs use both 5 V and 12 V. Here, 12 V is the signal voltage to the motors, and 5 V is used to operate the software on the SMCs. The three-phase 12 V power signals from the ESC go into a 3-pin plug, then through wires, and finally into the MacArtney connector. The four-phase 12 V power signals from the SMCs pass through the PCIe-x4, then into two 6-pin connectors, and finally into the MacArtney connectors.

The temperature sensor circuit on PCB-ManPu is identical to that on PCB-NavCon and is powered by 3.3 V. However, as there is initially no 3.3 V supply on this board, it is routed from PCB-NavCon to PCB-ManPu through the PCIe-x4.

The manual control system lets the pilot control the motion of the ROV by using two Xbox controllers, one for the thrusters and one for the manipulator. The microcontroller on the development board receives a value from -100 to 100, in both the x-axis and the y-axis, from the Xbox One controller. The x- and y-axis controls the ROV in the horizontal plane. Where the x-axis runs along the length of the ROV and the y-axis along the width. These values are used to calculate the throttle needed on each of the thrusters

[4]ESC: Electronic Speed Controllers
[5]SMC: Stepper Motor Controllers
[6]BLDC motor: Brushless Direct Current motor

to move the ROV in the direction given by the values. The pilot is also able to manually control the yaw and heave of the ROV. The horizontal thrusters are exclusively controlled manually by the pilot, but the vertical ones are also controlled automatically.

Three PID controllers are implemented on the control unit in order to realise the stability control of the ROV. The purpose of the stability control system is to ease the pilots task of manual operation by automatically counteract rolling, pitching and depth drifting. Therefore, the three PID controllers are controlling one degree of freedom each: rolling, pitching and heaving. The PIDs are realised through a feedback loop from the sensor system, which contains an IMU for reading the roll and pitch angles, and a pressure sensor for reading the depth. The controller parameters were found through mathematical modelling of the system in the first place, and after the first water test, they were fine-tuned in order to obtain a more optimal stability control. One of the main advantages of the stability control, is to prevent the ROV from pitching while holding heavy objects with the manipulator arm.

As previously stated, the pilot has the ability to control the depth of the ROV manually. This is done by pausing the PID controller responsible for the heave control. When the pilot stops adjusting the depth of the ROV, the PID controller automatically resumes operation with the new depth being set as the new reference point.

The use of 8 thrusters with 12 VDC creates a need to limit the amount of power used, such that the ROV never exceeds the maximum allowed current of 30 A (ELEC-008E). This is done in the microcontroller by giving the PID controllers limited amount of power and also by limiting some of the movement controlled manually.

Topside System

The topside system consists of a Mini-PC, two portable monitors, two Xbox controllers, a speaker, a keyboard, and, a mouse. A visual display of the topside system can be seen in figure 28. Due to the compact design of the control station, the whole system, excluding the power supply, can be carried inside a bag. Communication between the topside and the ROV goes through a Ethernet cable. After the control station is set up, only power and Ethernet cables must be connected to the ROV to complete the setup procedure. The whole procedure takes approximately 2-3 minutes to set up.

Figure 28: Topside system setup.

The program is installed and run on Ubuntu Linux. The Xbox controllers are wired to the mini-PC and function as plug-and-play. One of the controllers is responsible for maneuvering the ROV and the other is responsible for controlling the manipulator.

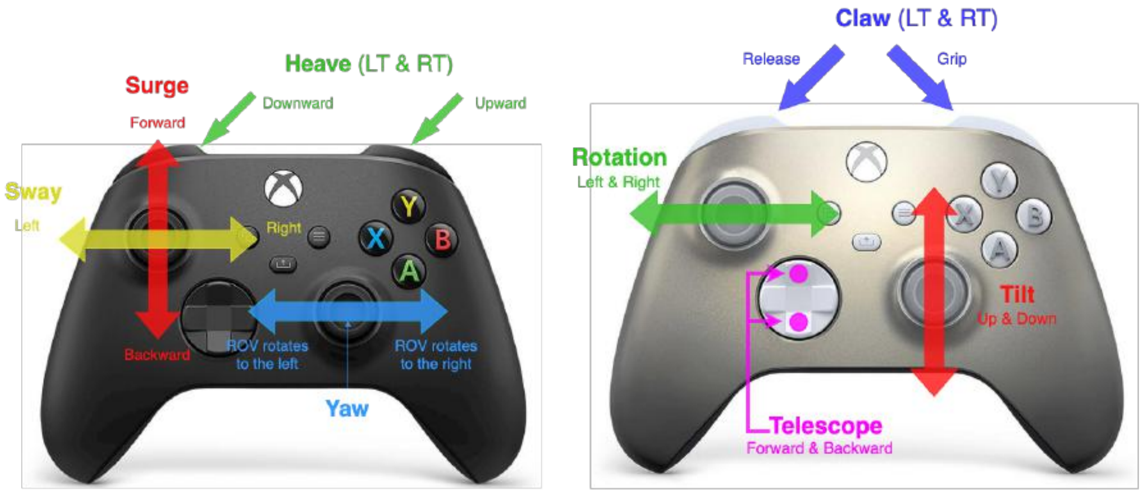
The topside program has 5 parts, the GUI (Graphical User Interface), a network handler, a controller handler, and an autonomous handler, and the main program that integrates these functionalities. The topside program is written in Python using QT for the GUI, and OpenCV for image processing.

The GUI is made to best visualize information about the ROV, it displays the following data: Leakage alarms, sensor alarms, temperatures, depth, roll angle, pitch angle, and thruster output. Additionally, it contains buttons for different functionalities and activating different modes. The following modes can be activated from the GUI: autonomous docking, frog count, sea grass monitor and normal operation. Functions that can be toggled or operated from the topside systems are: camera tilt, on/off regulation of heave, pitch and roll, recalibrate IMU, recalibrate depth, on/off light and reset of fuses.

See figure 29 for a screenshot of the GUI:

Figure 29: Example screenshot of the GUI. Note all the different information displayed and the buttons binded to different functions.

The controls for the ROV and manipulator can be seen in figure 30a and figure 30b.



(a) ROV Controller (b) Manipulator Controller

Image processing

Image processing is done using OpenCV integrated with GStreamer, which allows frames to be processed in real-time. The frames from the camera feed are encapsulated on the Jetson (on the ROV) and sent to the topside. The image processing is done on the mini-PC topside.

Autonomous docking

The program for **autonomous docking** uses image processing techniques to find the red center point in the docking station. Using this as a reference point, it calculates how much it is displaced and how much it needs to move.

Frog count

The program for **frog count** uses image processing techniques to "see" the blue pipes defining the transect. With this information, the program calculates how it should move in order to follow the transect. While the ROV is maneuvering along the transect, it counts the frogs within the transect by distinguishing different shapes and colors.

Seagrass monitor

The program for **seagrass monitor** takes two screenshots of the before/ after of the seagrass. Then the program counts the green squares in the two images and calculates the percent difference in growth. In other words, if there was a positive or negative growth.

Safety

During the development process of the ROV and the float, there are several instances of danger that must always be taken into account, and kept in mind by all participants of the project. For the organization UiS Subsea, it is crucial that no damage is caused to, first and foremost, our own members and other people, but also not to equipment and facilities. In particular, a lot of potential hazards may arise during the production in the electrical lab and in the mechanical workshop, and during the testing phase by the pool. All the facilities that has been made use of by the members of UiS Subsea are provided by the University of Stavanger, and the university has established strict guidelines on conduct during work in certain areas. UiS Subsea demands compliance from all members that these guidelines are followed, and that everyone strives to reduce potential hazards as much as possible.

Electrical laboratory

The initial testing of the separate electrical units and the overall system was done in an electrical laboratory. Accompanying this, the University of Stavanger demands that all personnel using the laboratory has gone through a HSE course, before allowing them to operate on the lab. This makes sure that all work in the electrical lab is done in a safe manner, and that all members of the organisation knows the risks of operating in the laboratory, as well as means of mitigating the risks. Among the safety measures practiced, the use of a solder fume extractor, eye protection and ESD wrist bands, are some of the most important examples.

Mechanical workshop

To make sure every member of the organisation operates in a safe manner in the workshop at the campus, the University of Stavanger demands that all personnel using the workshop has to have an approved safety course issued by the operators of the workshop. Any work done with heavy machinery or dangerous tools has to be done under supervision of the operators of the workshop until they are satisfied that you are able to use the machinery by yourself. Safety measures in the workshop includes the use of standard work wear and eye protection, which is demanded, and provided, by the university.

Pool

Water testing of the ROV was done in a pool. Along with this, UiS Subsea demands that all members follows the safety routines during operations. This includes removing all equipment which is not vital for the operation, taking off shoes and verifying that connectors and strain relief has been attached correctly. This is done to prevent injures caused by stumbling, slipping and electrocution. In addition at least one of the personnel at the poolside has to have completed a Norwegian lifeguard course.

Project management

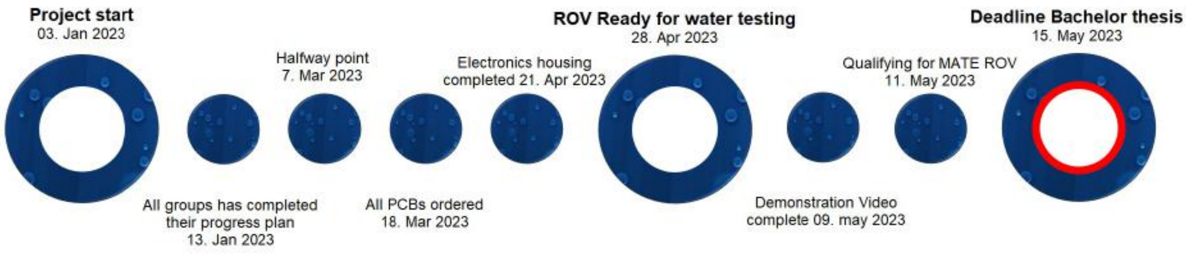
The management of UiS Subsea is divided into two different parts. One part consists of a team of eight students whom are responsible for the daily operation of the organization. This team is responsible for staying in contact with sponsors, attracting new sponsors, accounting, budgeting, expense reimbursement and managing social media accounts.

The other part of the management includes five students. These student are responsible for the project itself, where the roles are divided into project leader, competition responsible, CTO mechanical engineering and CTO Hardware and CTO Software. By splitting the organisation in this way, the daily operation needed for running UiS Subsea are independent from the project. This makes sure that the progress of the project are not halted by daily operations.

The need for students from different fields of study in the project, has demanded cooperation beyond the usual amount for a standard study program. Each group are developing their own subsystem for the project, but the key for completing the vessels is managing to put all the subsystems together. To accomplish this, the project management have arranged meetings with representatives from all groups, every Monday since the project started. In addition, UiS Subsea are assigned an office at the University of Stavanger dedicated to the members of the organization. Throughout the entire project, every group, or at least members from every group, have been present at the office on a daily basis. This has proved to be a decisive factor in order to complete the vessels.

Since every member of the organization are writing their bachelor thesis based on the project, and the students were busy with other subjects last semester, the development process didn't start before the beginning of January 2023. The late start has proven to be a challenge throughout the whole project. Vital components of the ROV took a long time to complete, and the deadlines that was set before starting, were difficult to comply fully with. The most critical delay experienced was the latency of the water test of the vessels, which was initially planned to be the 11th of April, but ended up being the 28th of April. Despite the time difficulties, the project was successfully completed, sending the qualification video before the deadline. Some components was not completely finished at this point, but final adjustments are to be made before the competition.

The main milestones related to the project with the associated dates of completion are shown in the figure below.



Cost planning

UiS Subsea has a tradition of leaving about 100 000,- NOK for the next years project. This means that next years project already has the funding needed to start building a ROV before additional funding is needed. The biggest cost involved in the project is the cost of travelling and competing in the US.

Since the ROV is already funded and the University of Stavanger, which is our biggest contributor, yearly donates more than what is needed to build the next ROV, the remaining cost to cover is the travel expenses. Through different local companies, some of the travel expenses are covered, but every student who travels to the US will have to pay some of the cost themselves.

Therefore, any expenses exceeding the 100 000,- NOK in the original budget increases the amount every student will have to pay to travel, but do not put the company at any risk.

Since the team is divided into nine different teams, working on separate tasks in designing and building an ROV, every group has an initial budget to complete their part. If a group should need to use more money than allocated, they would need approval from the chief financial officer. In figure 31, the budget for each team and the amount used is shown.

Group:	Budget	Amount Used	Remaining
ROV and float-design (ME)	kr 12000,00	kr 2831,43	kr 9168,57
Manipulator (ME)	kr 8000,00	kr 1009,55	kr 6990,45
Graphical User interfase (CS)	kr 2500,00	kr 1498,00	kr 1002,00
3D-modelling and autonomous functions (CS)	kr 2500,00	kr -	kr 2500,00
Control system (EE)	kr 3000,00	kr 8194,09	-kr 5194,09
Sensor system (EE)	kr 6000,00	kr 1920,91	kr 4079,09
Power supply system (EE)	kr 10000,00	kr 8431,00	kr 1569,00
Comunication and image processing (EE)	kr 10000,00	kr 12211,09	-kr 2211,09
Float system (EE)	kr 8000,00	kr 5939,83	kr 2060,17
Generel components for ROV	kr 45000,00	kr 45911,40	-kr 911,40
Organization and social events	kr 9000,00	kr 14979,00	-kr 5979,00
SUM NOK	kr 116000,00	kr 102926,30	kr 13073,70
SUM USD	USD 10661,76	USD 9460,14	USD 1201,63

Figure 31: Overview of costs. Currency in NOK. Sums given in NOK and USD. ME indicates Mechanial engineers, CS indicates Computer Science and EE indicates Electrical engineers.

Some ammount below the budgeted 116 000,- NOK were used on the project. Most of the groups used about as much money as the budget allowed them to. Some groups came in well below there budget from reusing older components. The general components budget was not as big as it needed to be, because of the cost of thrusters and connectors. Luckily, the remaining groups in average needed less than were allocated to them, and the total cost ended up being satisfying regarding the overall budget.

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