Team Little Mermaid TOSCE ROV

Aarhus School of Engineering, Aarhus, Denmark

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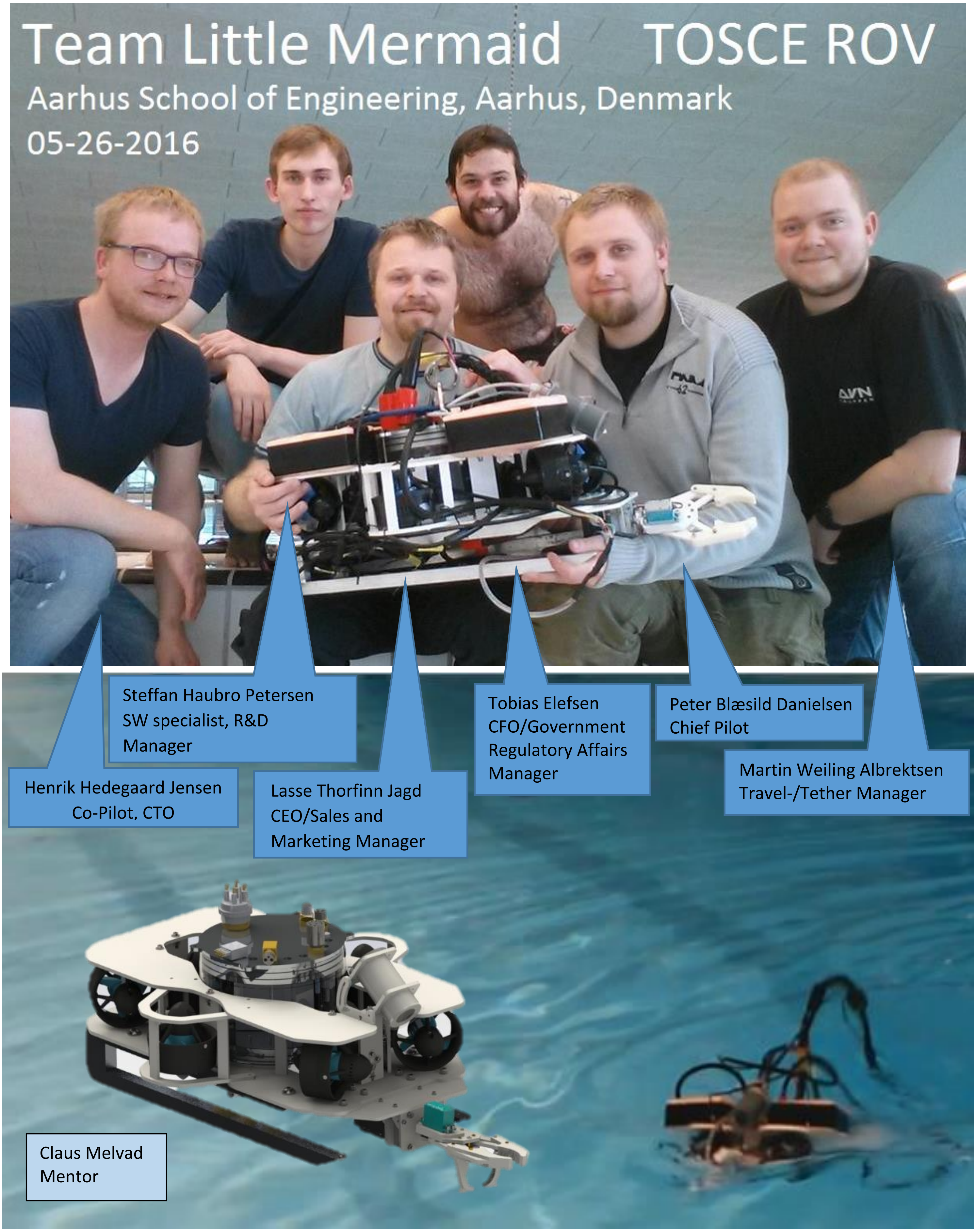

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Abstract

The Tether Operated Submersible Coral Explorer Remotely Operated Vehicle, TOSCE ROV is a merge of two different ROVs. The basic idea was to make two ROVs, as part of two bachelor projects. The best solutions from each prototype, assembled into one ROV.

The TOSCE ROV is a response to a request from the Marine Advanced Technology Education Center, for a compact, lightweight ROV capable of getting oil samples, comparing coral colonies, recovering sensitive equipment and doing underwater installations. This report created by team Little Mermaid, a subdivision of Aarhus University, illustrates and presents the different tools and function of the TOSCE ROV, with respect to the different missions.

The TOSCE ROV is a combination of high quality, high performance industrial solutions and creative, well-researched, in-house development. Designed to use the least, time-consuming manufacturing processes and taking advantage of newer technologies, with a faster prototyping speed, such as 3-D printing and laser cutting. The TOSCE ROV is a result of four months intensive work by the six

members of the team. Custom designed to be lightweight, compact and to meet the mission requirements.

For easy orientation of tools relative to the ROV, two different camera positions increase the pilots' view. The electronics housing is transparent polycarbonate tubing and aluminum end caps for increased cooling efficiency of DC-DC converters and thruster ESC's. The TOSCE ROV utilize six degrees of freedom for increased stability in all operation scenarios.

Design

ROVs take many shapes and sizes and are used extensively by the science community to study the ocean.
To design an ROV at least three engineering disciplines are needed.

- Mechanical Engineering
- Electrical Engineering
- Software Engineering

Team Little Mermaid consists of Mechanical Engineers only, so a lot of the needed skills to implement Electrical and software systems had to be learned in parallel with the project

An ROV act as a free body under water. It is therefore crucial to incorporate stability in the design. The stability of an ROV has a decisive influence on its ability as a tool. The relationship between weight and buoyancy need adjusting, such that it achieves near neutral weight in water. Thrusters, center of gravity and floats, need to be placed such that stability is achieved in all directions. It is also advantageous to incorporate a compensation feature to counteract the increased imbalance when grabbing an object. And like any other unmanned vehicle, the pilot need all the visual aiding hardware he can get.

Considerations when designing the ROV:

- It must be made of lightweight materials
- It must be small in size
- It must be designed with ease of manufacturing in mind
- Visual aiding hardware such as cameras and perhaps sonar must be present
- Cost of components

One of the main challenges in designing an ROV for the contest is the restriction on size. The ROV can under no circumstances exceed 85 cm in diameter using the two largest dimensions of the ROV.

The NASA prospect of the project is linked to the fact that a mission to Europa is set to launch in the decade 2020-2030. The weight of the ROV is an important design criterion as well, giving the fact that every kilo launched into space cost in the excess of 20.000$. It is the goal of Little Mermaid to design an ROV that makes no compromise on the highest restriction level presented by the MATE manual 2016.

Design process

The design process started with the goal of designing an ROV with all the necessary features to complete the tasks specified in MATE manual 2016, with maximum points. Two teams with three students each were to design a ROV for each team. By following the design process, illustrated in Figure 1, the two teams were able to come up with two completely different designs with different approaches to solving the tasks. A morphology analysis was used for selecting the best solutions for each task. Concurrent design was introduced to optimize the design process within the timeframe at hand.

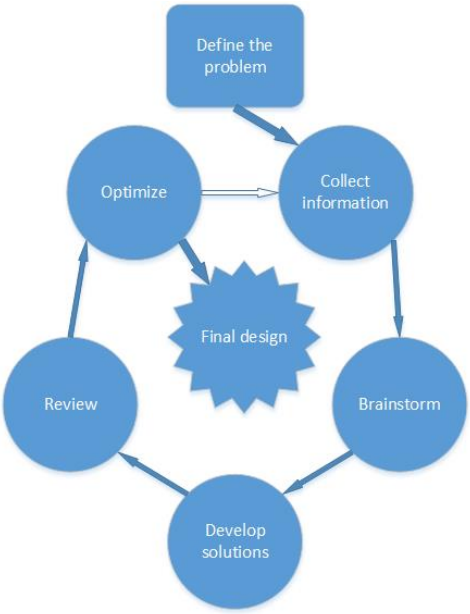


Figure 1 - Design process illustation

After a mini regional contest, the best solutions from each ROV were merged into one ROV. Designed to be produced by 3-D printer and laser cutter, as much as possible, reduced production time significantly, and meant the company had sufficient skill to manufacture it without professional help.

Thrusters

TOSCE ROV is designed to have six degrees of freedom, with eight thrusters. T200 and T100 thrusters from Blue Robotics were chosen for their performance vs. price ratio, well tested, encapsulated and CE certified. Four vectored T100 act as thrusters in the horizontal plane, and four T200 as vertical thrusters to be able to carry four CubeSats.

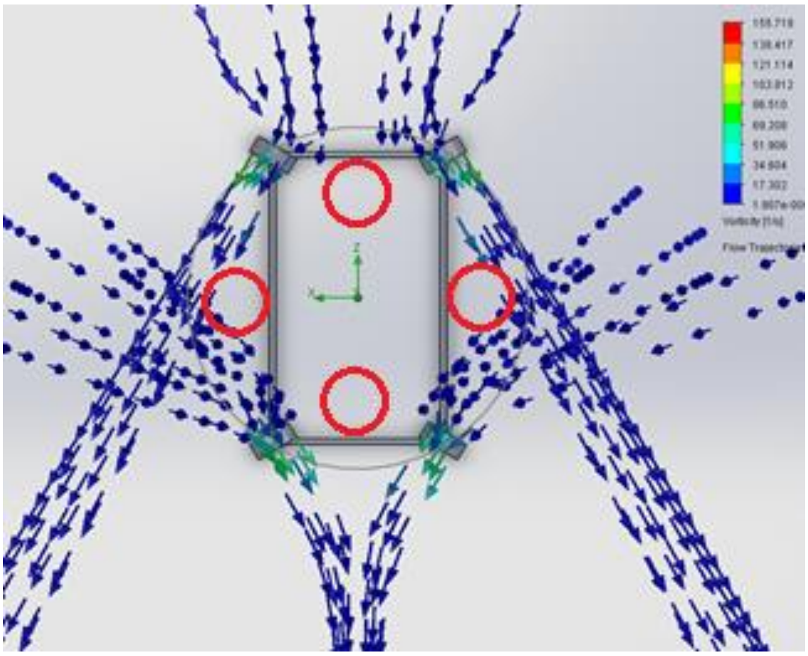


Figure 2 – SolidWorks Thruster flow simulation results and vertikal thruster placement

Horizontal thrusters are angled 31 degrees in respect to forward direction. Vectoring the thrusters with this orientation gives a maximum forward, reverse and sideways thrust of 61N and 37N respectively.

The 31° are based on a series of simulations, made I SolidWorks, to determine what angle would cause the least interference between the four thrusters, decreasing the overall efficiency of the thrusters, see Figure 2.

Vertical thrusters are not angled, because extra power for strafing is not needed. This gives a maximum upwards and downwards thrust of 160N respectively. The four thrusters are positioned such that they have minimal interference on the flow from the horizontal thrusters. This positioning can be seen on Figure 2, indicated by the red circles.

Chassis

The design of the chassis for TOSCE ROV is based on a topology optimization done in Inspire. In the topology, optimization the thruster faces are applied their respective forces on a base model, within the boundaries of a 580 mm sphere. This results in the rectangular for the chassis seen in Figure 3.

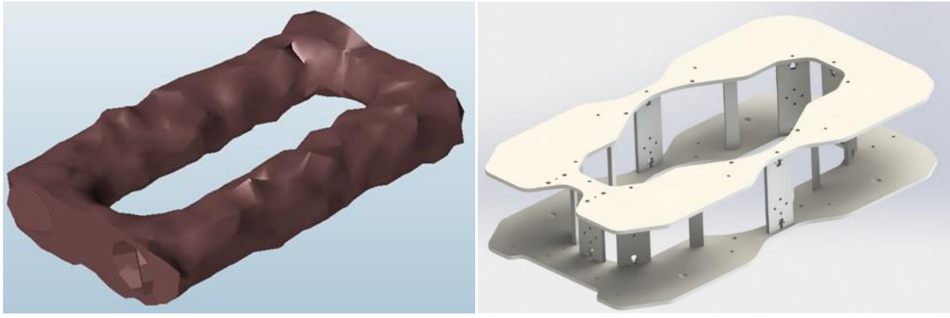


Figure 3 - Topology result and final chassis

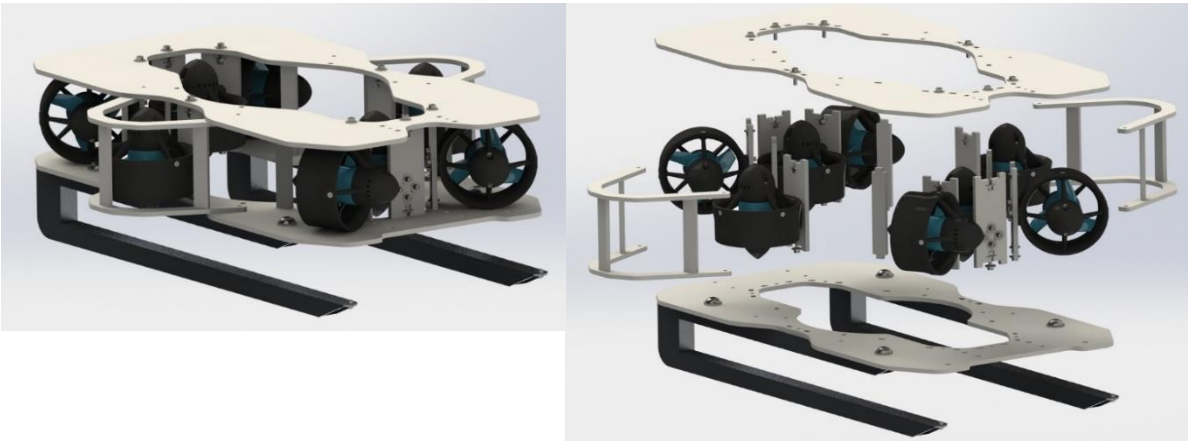


Figure 4 - Completed chassis

All parts are laser cut from 5 mm ABS plastic sheets, which are then bolted together by using the T-slots in the vertical plates. The complete chassis is shown in Laser cutting is used because of its relative ease of use and speed, since cutting out an entire chassis only takes about two hours.

The thrusters are mounted on the vertical plates, and the protectors for the side thrusters are mounted on the sides. The stands are mounted on the bottom of the chassis and serves to pick up CubeSats, which is further explained in Aluminum stands/forks.

Materials

The material for the chassis must be strong and lightweight, it also has to be off-the-shelf, because of the limited timeframe. Different types of plastic and aluminum is evaluated, based on their properties in order to find the most suitable material.

Material	Stock	Price ($/kg)	Density (kg/m^3)	Stiffness / strength [Yield Strength (MPa)]	Water absorption (%) (24 Hours)
POM	A bit (5 mm)	18,6	1390	71.5	0.25%
Acrylic	Plenty (3, 4 & 5 mm)	21,6	1200	45	0.20%
PVC	None	10,2	1300	40.7	0.06%
ABS	None	9,4	1020	30	0.30%
Polycarbonate	Ordered (5 mm)	24.1	1200	65.5	0.12%
Aluminum	None	12.6	2700	300	0

Table 1 - Materials for chassis

All materials that cannot be cut by laser cutter available, is discarded. That being, PVC, polycarbonate and aluminum. When PVC is cut in a laser cutter it separates the hydrochloric acid gases that make it extremely dangerous to work with. Polycarbonate can be cut, and it is not dangerous, but it is so poorly thermally conductive so it has a tendency to melt or ignite during cutting. The available CO2 laser cutter is only at 50 Watts, and aluminum has a relatively high density, the aluminum plate is also discarded as a possibility.

After the elimination process, 3 choices remain to be scored, as seen in Table 2Table 2 - Scoring table for chassis material. Every criteria gets a factor that reflect the importance of the criteria.

Material	Stock [2]	Price [2]	Density [3]	Stiffness/strength [2]	Water absorption [1]	Score
POM	2	2	1	4	3	21
Acrylic	5	3	3	2	2	31
ABS	1	4	5	1	1	28

Table 2 - Scoring table for chassis material

Based on the scoring table, acrylic is the most suitable materials and the chassis will be designed so it can be cut in the 300x600 mm sheets, which are available at the university. A prototype of the chassis is produced in 4 mm acrylic sheet.
There was some concern on how the prototype would hold up in the event of a heavy bump or crash. A "crash test" was commenced (thrown on the floor), which proved the concerns right. A 5 mm ABS sheet was used instead for the new chassis.

Electronics canister

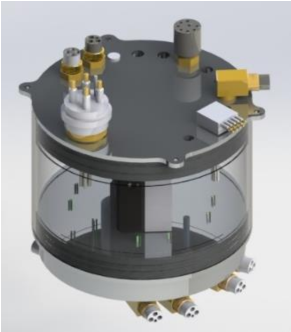


Figure 5 - Canister for Electronics

Water and electronics is a bad cocktail. To prevent disasters caused by leakage a housing for all the electronics is constructed. A transparent polycarbonate tube is used for the following reasons.

- It is possible to visually inspect the insides for possible leak.
- To check LEDs on the myRIO, GigE switch and DC-DC converter.
- Easy to manufacture

Two CNC-milled aluminum caps, each with a double O-ring, to ensure that the electronics stay dry, is used as end-caps. Aluminum is chosen because:

- It is a lightweight metal
- It is a good thermal conductor, transporting heat away from the DC-DC converters and ESCs.
- It is very machinable.

The canister is designed with ease of assembly/disassembly in mind, as you only need to remove the top cap to access all of the electronics inside. A valve is mounted to ease opening and closing the canister. SubConn connectors are used for all external connections to make sure that they are waterproof and keeping a good connection.

Figure 6 - Exploded view of canister

The housing has been tested in saltwater at a depth of thirteen meters for 20 minutes, without any leaks.

Mission-Specific Tools

One of the critical components of the ROVs ability to solve the tasks set out by MATE is the manipulator.

Gripper

The gripper is the main tool of the ROV. To find the best solution a morphological analysis was conducted. A brainstorm with all the different ideas and designs lead down to three concepts.

- Translating gripper
- Sprocket Gripper
- Spindle gripper

Figure 7 - Translating gripper

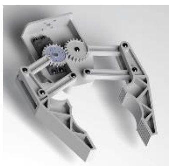


Figure 9 - Sprocket gripper

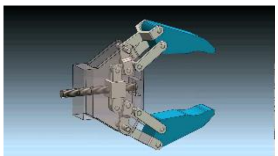


Figure 8 - Spindle gripper

These concepts were scored as seen in Table 3.

Solutions	KISS (3)	Light and compact (2)	Stability/strength (2)	Price (1)	Ability (3)	Total Score
Translating gripper	5	3	5	5	4	48
Sprocket Gripper	4	5	4	5	5	50
Spindle gripper	1	1	4	3	3	32

Table 3 - Score table for gripper design

With a score of 50, the sprocket gripper design was chosen.

This multipurpose tool as shown in Figure 11, is able to grab and rotate. The two 3-D printed jaws are parallel closing and driven by a BlueRobotics Servo HS-5646WP[1]. Other parts, except the aluminum bracket, are made from 5mm ABS. When turning one of the ABS-arms of the gripper with the servo, a gear turns the other arm in opposite direction. The tip clamp force of the gripper is 8.7 N. Each jaw has a perpendicular hook, which forms a circle when the gripper closes. These hooks are specifically designed for the ESP connector and colleting oil samples, as seen in Figure 12.

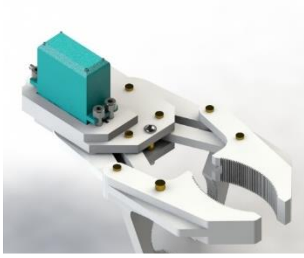


Figure 11 - Assembled gripper

A stepper motor rotates the gripper, with a torque of 0.7 Nm. The heaviest load the gripper has to rotate will be the CubeSats. In worst case, CubeSat weighting 25 N under water, and with the best possible grip, shortest distance to centroid 8.5 cm, the required torque will be 2.1 Nm for a half turn.

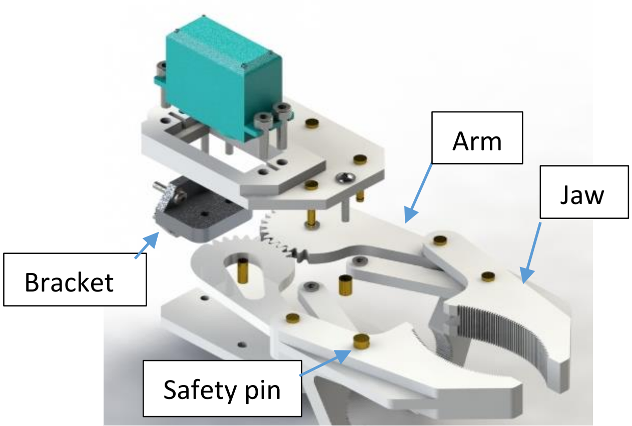


Figure 10 - Exploded view of gripper

Figure 12 - Collecting oil sample

Tests done with CubeSats, following the specifications in the probs manual, showed that the manipulator were able to turn all CubeSats easily. Objects can also be turned by rolling the ROV. As a safety feature a removable pin was introduced on the gripper.

[1] https://www.bluerobotics.com/store/servos/hs-5646wp/

Aluminum stands/forks

TOSCE ROV is equipped with two multi-purpose 48 cm forks, also acting as stands, see Figure 13. The forks are made from welded 20x20x2 mm aluminum square pipes, which are bolted to the bottom of the chassis. The forks serve three purposes.

- Structural support and rigidity
- Protects bottom connectors
- Used for collecting CubeSat's.

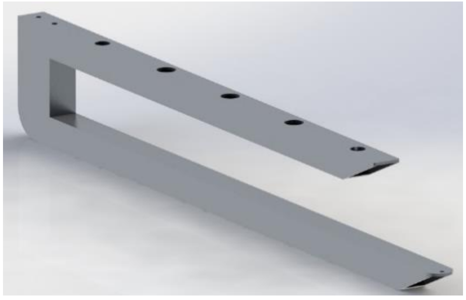


Figure 13 ROV aluminium stand/fork

When on surface the ROV will be supported, so no harm comes to the connectors on the bottom end-cap. They are designed to be capable of carrying two CubeSat's each, making it possible to transport all necessary CubeSat's in one go. Unloading the CubeSat's can either be done by reversing the pickup, or by tilting the ROV forward.

Buoyancy

Figure 14 Float placement, indicated by the red numbers

TOSCE ROV is equipped with a foam based float system to make it slightly more buoyant than neutral. This is done to insure a safe return to the surface in case of power shortage or thruster failure making the ROV incapable of a powered ascend.

The floats are designed to fit the top surface of the ROV to increase stability; the red numbers shown on Figure 14 indicate float placements. The amount of the buoyancy needed, is determined using Archimedes principle, see Figure 16[2]. The length between the center of gravity (CG) and the center of buoyancy (CB) determines how stable the ROV is, without thruster interference. The stability is the size of the righting torque applied to the ROV, as shown in Figure 17[3]. BG is the distance between CG and BG.

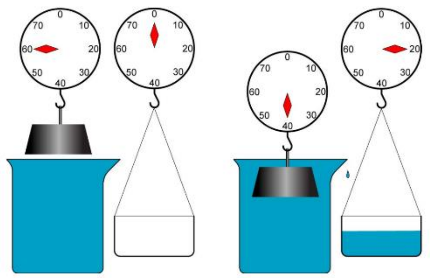


Figure 16 Archimedes principle: the power from buoyancy is equal to weight of the water displaced by the object

To find the force acting on the ROV at CG, $total\ weight[kg] * gravity\left[\frac{m}{s^2}\right] = Weight\ force[N]$ and finding the forces acting on the ROV at CB,

[2] http://cornerstonerobotics.org/curriculum/lessons_year3/eriii9_buoyancy1.pdf
[3] http://cornerstonerobotics.org/curriculum/lessons_year3/eriii10_buoyancy2.pdf

$total\ weight\ of\ displaced\ water[kg] * gravity\left[\frac{m}{s^2}\right] = Bouyancy\ force[N]$. With these two forces, besides finding the righting moment, the ROV's ability to float can be found to be true if $F_b > F_w$.

The tether floats are placed in one-meter increments, such that the first 13 meter of the tether is positive buoyant, thus making sure it stays on the surface of the water. To prevent the tether from interfering with the maneuverability of the ROV, the remaining 12.2 meters are made neutral buoyant, preventing it from constantly pulling the ROV upwards.

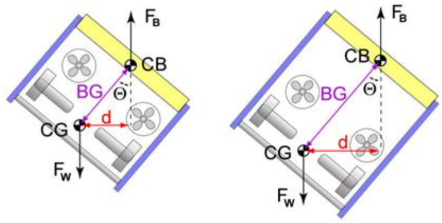


Figure 17 Stabilization torque – $T = F_w * d$ *or* $T = F_w * BG * sin(\theta)$

Electrical Systems

The control unit of the ROV is based on the NI myRIO development platform. It has a dual-core ARM Cortex-A9 real-time processing and Xilinx FPGA customizable I/O. With LabVIEW it is relatively easy to program sensor software, PWM control and PID processing.

All electrical components besides motors, cameras and the temperature sensor are placed in the canister.

- Five Vicor 3:1 DC-DC step-down converters, converting at least 43.6V volts to 14.5 volts, to power the ROV
- Eight 30A ESCs from BlueRobotics as truster drivers
- Two No-name DC-DC converters
- National Instruments myRIO
- Netgear Prosafe GS 105 GigE Switch
- Big easy Stepper driver
- Kistler 4260A pressure sensor
- 18 bit ADC Board for I2C

Components with a high heat dissipation, like the five Vicor DC-DC converters and the eight ESCs, are mounted directly in the top aluminum endcap. This configuration serves three purposes.

- Heat will be dissipated a lot faster through aluminum to the water. This increases stability and prevents breakdowns
- Power connector from the tether is connected at the top cap. By placing main DC-DC converters at the top next to the connector, high current leads will have the shortest route
- If a leak should occur, the chance of salvaging the ROV without burnout is increased

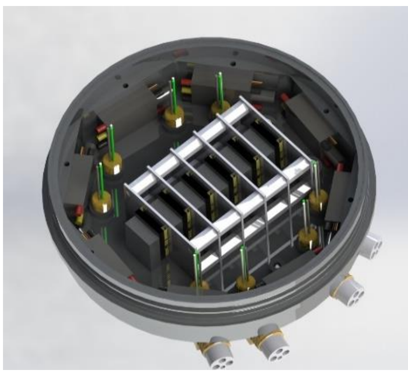


Figure 18 - DC-DC converters and ESC's mounted in top cap

A separation of power and communication components including wires, is done to counteract electro-magnetic interference (EMI). An aluminum shielding plate separates the main DC-DC converters and ESCs from all the sensitive components, such as ADC board and myRIO.

Three separate adjustable DC-DC converter, power the servomotor for the gripper, and gives power to the myRIO, GigE switch and cameras. These parts are protected with 2.5A fuse, as seen in the SID, appendix A1.

Tether

Figure 19 - Tether strain relief

To communicate and power the ROV, a tether with data and power cables is needed. The tether is designed to operate at depth of up to 12.2 meter without reducing the maneuverability of the ROV.

Power cables made from copper wires are heavy, so to keep the overall weight of the ROV to a minimum the tether is made from copper cladded aluminum (CCA). The power cable weighs 3kg with a length of 25 meter and is designed for a fuse limit of 35A. The power cable consists of two parallel connected AWG 10 lines, giving a total to four leads, normally used as high power speaker cables, Hollywood ENERGITIC speaker cable HE-3200[4]. This gives a maximum voltages drop of 4.4V along the length of the tether, giving the TOSCE ROV an operating voltage of at least 43.6V before downscaling the voltage to 14.54V with the Vicor DC-DC 3:1. This voltage is within the desired voltage range of 14-16V. The data is carried through a cat6 Ethernet cable with a reinforced rubber cap, to protect the cable from general stress and strain. The tether is connected to the ROV with two SubConn connectors, and a stress relief mounted to the canister.

Sensors

Cameras

Good pilot vision is a very important feature of an ROV. TOSCE ROV is equipped with a GigE PointGrey camera pointed directly at the gripper, as seen in Figure 20. The PointGrey camera is enclosed in a canister, as it is not itself waterproof. The lens mounted on the camera gives a 120° field-of-view. An analog Aquacam is mounted under the ROV, giving vision along the aluminum stands/forks. The analog camera also provides vision, when using the extra jaw on the gripper, for oil samples and CubeSat's, Figure 20. This camera is depth rated to 45 m.

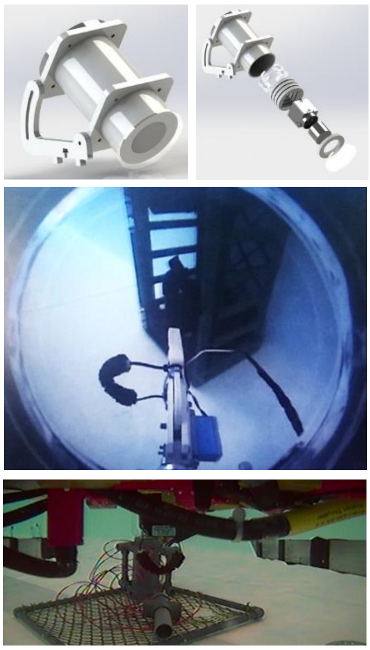


Figure 20 - From top to bottom, Aquacam ROV bottom view, ROV front view, point grey camera,

[4] http://www.hollywoodsoundlabs.de/customer/web/indexhw.htm

IMU Vector NAV

When the time came to pick an IMU, Vector NAV was kind enough to donate a VN 100 rugged to the ROV project. It uses a sensor fusion algorithm, which in short combines the sensors gyroscope output with its accelerometer output. This gives a responsive and accurate output with no drift. The MPU-6050 was tested as, another less expensive alternative to the VN 100. It proved incompatible with the stabilization software, because of a slow update speed, resulting in low reaction times. Another reason for choosing the VN 100 instead of the MPU-6050 is that its sensor fusion algorithm has a several minute-long calibration time, on every startup. The IMU is a commercial product, to save time and getting an earlier function test done, for the ROV's stabilization software.

Pressure sensor

The pressure sensor comes from Kistler, and has a 0-5V signal and an accuracy of ±3 cm. For the signal to be interpreted by the myRIO a conversion need to take place. Unfortunately, the myRIO's analog inputs has an accuracy of ±37.5 cm, so a better analog conversion was needed. An Ere I2C-AI418S ADC was chosen. The accuracy on this board is ±1.6cm, which kept the inaccuracies within the specified ±10 cm. The Kistler is factory calibrated ensuring the promised ±3 cm accuracy. Confirmation of the accuracy happened by using a DRUCK DPI 612 Flex pressure calibration unit, with an accuracy of 1 mbar. The two main reasons for choosing the Kistler are time and quality insurance. It was deemed too time consuming to make a likewise compact accurate sensor in house.

Temperature sensor

For the temperature sensor a DS18B20 was chosen. The sensor is factory calibrated and promises an accuracy of ±0.5°C which is well within the margin of ±2°C. A accuracy test of the sensor was done with a AMETEK ITC-155A calibrator with an accuracy 0.18 °C, and all measurements fall within the 0.5°C margin specified.

Figure 21 - DS18B20 Temperture sensor

Stabilization

As stated in the design section, stability of the ROV is of high importance.

TOSCE ROV is equipped with an IMU, Integrated Measuring Unit, to make controlling the ROV easier for the pilot. The ROV is constructed to level itself when placed in the water without thruster input. The stabilization keeps the ROV level when outside forces act on it. To make the stabilization easy and precise, a set of two thrusters are placed along the pitch direction and likewise for the roll direction, see Figure 22.

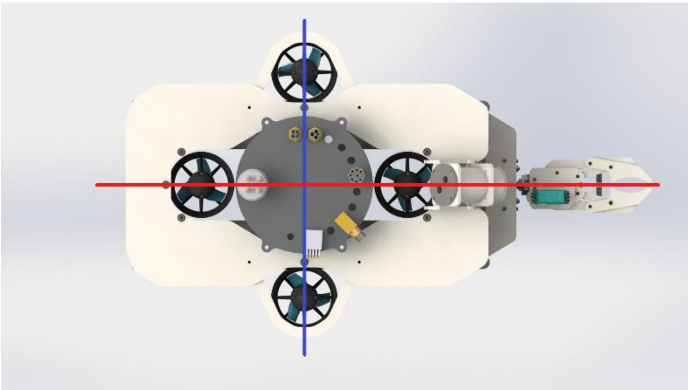


Figure 22 – Topside view of ROV. Pitch (red) and roll (blue) direction relative to the thrusters

This stabilization is convenient when lifting lost operation equipment, inserting connectors or for general operations in environments that can affect the ROV. To keep the ROV levelled despite these changes, the IMU measures the pitch and roll angles. The angles are processed and the PID software sends a signal to the thrusters compensating for any changes, such that the ROV is at the desired angle.

The control of the ROV in general is improved with the IMU. It allows the pilot to control the pitch and roll in angles instead of by feeling, visual control. This changes the controller's input to angels, instead of a thrust percentage. Letting the software keep the ROV stable makes it easier for the pilot to control it, because he does not have to think about correcting the thrust output to maintain stability. The IMU stabilization helps the pilot keep the ROV level when lifting object such as the Cube Sats or when doing underwater installations, like connecting the ESP and connector, as seen in Figure 23.

The IMU used is a VN 100 Rugged, kindly donated by Vector NAV for the project. Chosen for its 200 Hz update frequency and stable output. It uses a sensor fusion algorithm, which in short combines the sensors gyroscope output with its accelerometer output. This gives a responsive and accurate output with no drift. The MPU-6050 was tested as, another less expensive alternative to the VN 100. It proved incompatible with the stabilization software, because of a slow update speed, resulting in low reaction times. Another reason for choosing the VN 100 instead of the MPU-6050 is because the sensor fusion algorithm have a several minute long calibration, on every startup. The IMU is a commercial product, to save time and getting an earlier function test finished, for the ROV's stabilization software.

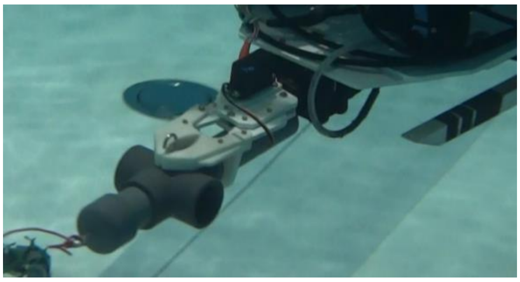


Figure 23 - Collecting ESP connector

The stabilizations function is to compliment the pilot and if he encounters a situation, where he finds it more trouble than help, a disable function ends the stabilization function.

Several tests have been made to confirm the usefulness of the system. The ease of piloting was significantly increased when the final adjustments were made to the software. Especially the EPS and wellhead tasks proved the usefulness of the system.

Final ROV Concept

After the ROV parts was manufactured, the ROV was ready for assembling. Five main assembly parts represents the final design.

- Canister
- Camera canister
- Rotation part
- Gripper
- Chassis with stands

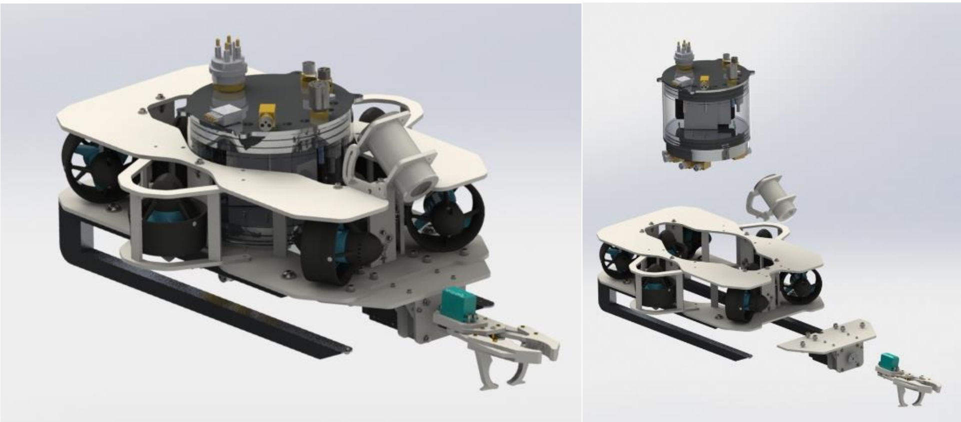


Figure 24 - Final ROV design

Programming

Using the myRIO development board as a platform it was decided to use LabVIEW as programming language. This decision was made because of the compatibility between the myRIO and LabVIEW, but also because it is very fast and intuitive for non-programmers. The FPGA, Field-Programmable-Gate-Array, is a very versatile chip, which can be programed with all sorts of functionalities to be executed as in a hardware-chip.

There are three different software programs needed to control the ROV.

- FPGA program
- myRIO RT program
- Surface PC program

The myRIO have eight dedicated PWM output ports. With eight thrusters and two additional motors, two more PWM port are necessary. The myRIO platform is totally customizable and it is programmable via the FPGA module in LabVIEW. Software for the FPGA is created with:

- Ten PWM outputs
- DS18B20 sensor capability
- DIO and analog ports

To control the ROV and relay information from topside to the relevant components, a myRIO Real-time software was created to handle all the information from the various different sensors. It is also in direct communication with the FPGA.

Displaying the sensory information from the ROV and transform the joystick input to a thrust percentage is done from the surface pc software.

Condensing all the necessary information the pilot needed to see, is displayed in a camera overlay in such a way that he can look at the information and camera without changing what screen he is observing.

The control software uses a reactive algorithm that changes the input to the thrusters based on the input from the controller. To make sure that the vectored thrusters get the correct input, the reactive algorithm converts the output such that the movement of the ROV stay smooth.

For the complete software flowchart see Appendix: A3

Troubleshooting and testing methods

When troubleshooting an error one have to be very systematic. As shown in, troubleshooting starts with an evaluation of the problem. To maximize efficiency a maximum of two members of the team would work on the problem. When the cause was found the different possibilities of solutions was discussed. Each possible solution would be tested to confirm if it was working as intended. This action is performed on all the possible causes, ending with an isolated test of the component. In special cases all members were included in the process.

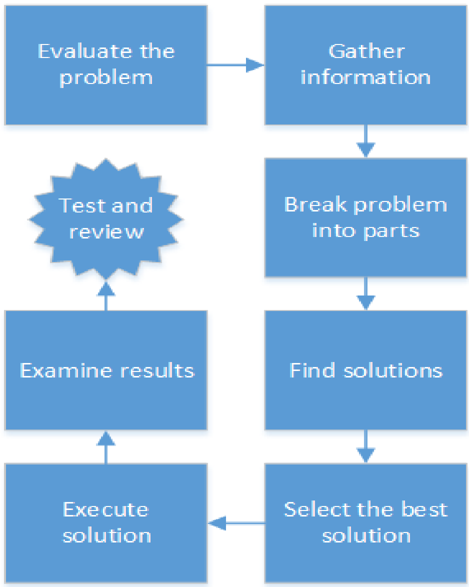


Figure 25 - Path of troubleshooting

In general, the different components were tested in a certain order;

1. Dry functionality test
2. Submersed in water and inspected
3. 24-hour shallow water submerse
4. 6 hours 5.5 m deep water submerse

The assembled ROV went through same procedure, but not step 3 and 4. The shallow water submerse went on for 6 hours, followed by a 2 m deep 12-hour endurance test. Tools were tested during this test and the results were recorded and compared to the goals set for the test. Unfortunately, no facility has been available to test at a depth of 12.2m. A test at sea is planned the 1st of Juli.

Improvements

Camera

A common issue for the pilot is the lack of depth vision. The angle of the front camera do not provide the sense of how far away objects are or a feeling of the ROV's is at the correct depth. The camera under the ROV tells the pilot if he is at the correct depth, but cannot be used to tell how far away objects are.

Stereovision positioned at the same position as the front camera, will provide the pilot the sense of depth. This eases tasks requiring high precision. To compliment this and increase the pilot's ability to ignore distractions, a VR head used to display the stereo vision, could be used. This could also make the ROV more intuitive to control by incorporating a dynamic vision via the VR headset to create a first person view.

To improve the visual design and create a more attractive product, the visual design of the ROV can be changed to get a sleeker look by changing the float design and a general color scheme made to improve visual cohesion.

Organisation

Team Little Mermaid, a six-person company specializing in short time, multipurpose, high quality ROV development has the ability to design, develop, test, evaluate and improve ROV's within just a few months of order placement. The staff of Team Little Mermaid being of a limited size, masters several roles and professional skills, each contributing to the structure and dynamics of the company. Company members, roles, project working hours, are shown in Table 4 - Company role overview.

Name	Role	Professional Skills	Working hours spent
Lasse Thorfinn Jagd	CEO, Sales-/Marketing manager	Electronics and Marketing	1208
Tobias Elefsen	CFO, Government Regulatory Affairs manager, Personnel manager	Physics and Methodology	1011
Steffan Haubro Petersen	SW specialist, chief software specialist, R&D Manager	SW development and Time management	1037
Peter Blæsild Danielsen	Chief Pilot	Mechanics and operations	1080
Henrik Hedegaard Jensen	CTO, chief electrical specialist, Co-pilot	Electronics development and Process managing	1030
Martin Weiling Albrektsen	Travel-/Tether manager	Materials and Produktion	1080

Table 4 - Company role overview

Time management

To complete the TOSCE ROV on time, a time schedule was made, see Appendix Schedule for a shortened version. This was used to help keep track of the individual task as well as managing the time spent and managing the resources of the company. The time schedule was created from the hard deadlines set by MATE as well as other external deadlines, from other parties. Each morning was started with a status meeting and a review of the time schedule. Tasks falling behind schedule were analyzed to determine the cause of the delay and extra relevant resources were allocated where needed. At the beginning of the project a task pool was created, so when employees completed assignments, they could take on new assignments themselves. This method proved effective as all employees are known to be hard working, enthusiastic and highly dedicated to the goal.

Financials

To maintain an overview of the finances of the project, a budget was made, as shown in Table 5.

Budget estimated	ROV 1	ROV 2	TOSCE ROV	Percent of budget allocated		
Tether	224.8	0.0	0.0	0.0	USD	Estimated
Electronics	786.9	786.9	449.7	0.1	USD	Re-used
Tools	112.4	112.4	149.9	0.0	USD	
Thrusters	562.1	786.9	0.0	0.1	USD	
Electronics housing	337.2	337.2	449.7	0.1	USD	
chassis	224.8	224.8	449.7	0.1	USD	
Materials	562.1	562.1	899.3	0.2	USD	
Airfare	0.0	0.0	8993.2	0.6	USD	
Living expenses	0.0	0.0	0.0	0.0	USD	
Budget Total	**2248.3**	**2248.3**	**10492.1**	1.0	USD	
Actual Spending Total	**3086.9**	**3651.5**	**4800.1**		USD	
Tether	**173.7**	**0.0**	**0.0**		USD	
Ethernet	23.8	0.0	23.8		USD	
Power	149.9	0.0	149.9		USD	
Electronics	**2721.6**	**3535.5**	**0.0**		USD	
Switch	22.5	33.0	22.5		USD	
myRIO	1247.8	1247.8	1247.8		USD	
16V DC-DC	524.6	524.6	524.6		USD	
7,4V DC-DC	7.5	6.5	14.0		USD	
Temperatur sensor	17.5	4.6	4.6		USD	
IMU MS5803	31.5	0.0	0.0		USD	
Pressure sensor	0.0	920.0	920.0		USD	
VN100 Rugged	800.0	0.0	800.0		USD	
VN100 connector	31.5	0.0	31.5		USD	
Power connectors	8.7	0.0	8.7		USD	
Anderson connectors	18.4	0.0	18.4		USD	
Small ethernet cables	43.5	0.0	43.5		USD	
Point grey camera	700.0	495.0	700.0		USD	
Camera lens	12.0	12.0	12.0		USD	
Leakage sensor	15.0	1.2	15.0		USD	
Current sensor	7.5	6.0	7.5		USD	
HS-5646-WP, Digital Servo	54.0	54.0	54.0		USD	
SubConn Connectors	1873.6	1873.6	5750.0		USD	
Steppermotor ms-23h242- 068-4b	0.0	69.0	69.0		USD	
steppermotor driver	0.0	20.0	20.0		USD	
SS Aquacam	0.0	320.0	320.0		USD	
TracoPower 12V	0.0	50.0	50.0		USD	
35A Fuse	134.9	0.0	134.9		USD	
ADC I2C board	0.0	27.0	27.0		USD	
Tools	**93.5**	**0.0**	**0.0**		USD	
Liquid gasket	10.5	0.0	0.0		USD	
Glue	29.2	0.0	0.0		USD	
Cleaning tools	8.8	0.0	0.0		USD	
Vulkanising tape	45.0	0.0	45.0		USD	
Thrusters	**0.0**	**0.0**	**0.0**		USD	
T200	1552.0	1164.0	776.0		USD	
T100	0.0	0.0	576.0		USD	
Materials	**98.0**	**116.0**	**0.0**		USD	
PC plate (5mm)	206.1	0.0	0.0		USD	
Ø200 PC pipe	374.7	374.7	374.7		USD	
Ø200 Aluminum pole	74.9	0.0	74.9		USD	
20x20x150 RK Aluminum Profiles	8.1	0.0	8.1		USD	
185x4 O-Rings	15.0	15.0	15.0		USD	
Aluminum plate260x260x30	0.0	50.0	50.0		USD	
ABS plate 5mm	0.0	36.0	36.0		USD	
POM	0.0	5.0	0.0		USD	
Akryllic plate 5mm	0.0	10.0	0.0		USD	
Airfair	**0.0**	**0.0**	**4800.1**		USD	
Budget/Actual spending Diff.	**-838.6**	**-1403.2**	**5692.0**		USD	
Total Technical Value	**8048.5**	**7319.0**	**12924.4**		USD	
Initial Budget	-	-	**14988.7**		USD	
Budget Surplus	-	-	**3450.2**		USD	

Table 5 - Budget

The initial budget was initially divided amongst the different posts marked with grey. As the project developed and parts where purchased the budget table was expanded. As indicated by Table 5, the construction of ROV1 and ROV2 took more resources than anticipated. This due to the particularly high price of the SubConn connectors. Other alternatives where therefore investigated, and cheaper alternatives where available, but was not of the same IP-rating as the SubConn connectors. Due to good previous experiences with SubConn connectors, these where decided upon, as even the smallest possibility of a water leak in the Electronics housing would be critical to the ROV. Fortunately, the TOSCE-ROV could be constructed entirely from previously used materials, and cheaper flights were found. The project came out with a surplus of 3450USD.

Table 5 should be read as follows: the PSU and tether is planned to be shared investment, therefore it only figures once, and many things will be reused and shared between ROV1, ROV2 and TOSCE ROV. However, a few backup funds are kept in reserve for the merging of the two ROV's into TOSCE ROV. The thrusters and PSU have been used in earlier projects or have been purchased on previous budgets, and therefore figure as zero. To conserve funds, items have been purchased with consideration to be reused for the TOSCE ROV. The actual spent budget is shown in Table 5.

Safety

At team Little Mermaid, the safety of the employees is paramount, during the development of ROV's. The company being of a limited size, in terms of personnel, team Little Mermaid has very high standards for the safety and welfare of its employees. This serves to reach the set deadlines, for the received tasks, while still maintaining the high quality and standards of its products.

Safety procedures

At team Little Mermaid, safety starts with yourself. We believe, accidents are best prevented by, giving our employees the theoretical, practical and technical knowledge, on how to operate and handle the tools, and machinery in the workshop. Therefore, company members receive education, training and guidance, through mandatory courses. These courses are held by our working partners, with many years of workshop experience in their respective fields, on how to operate the machinery, as well as safe and proper workshop behavior. These courses include, but are not limited to, the operation and performance of; band saw, column drills, lathes, welding and soldering, as well as applying proper ventilation and wearing proper safety equipment, which must be applied/worn at all times, when working in the workshop.

Safety check list:

To prevent accidents and or injuries while servicing, transporting, or handling the ROV, personnel must check and perform the following steps where necessary:

- ☐ Make sure the PSU is completely turned off
- ☐ Remove the tether from the ROV and PSU
- ☐ Make sure the tether is coiled neatly together next to the PSU
- ☐ Service, transport or handling of ROV must be performed by at least 2 company members

- Company members must wear closed toed shoes and safety glasses at all times
- Company members must wear tear- and non-electrically-conducting gloves
- All service, transportation and handling of the ROV must be performed at heights ranging from 1,0m-1,5m from the ground and must be performed no less than 3m's from water
- Before service of the ROV, gently touch the heatsink, with hands and evaluate if it is cool enough to touch comfortably
- When not in use, all tools must be placed in the provided toolbox
- Before ROV launch, ensure all O-rings are well in their groves
- Ensure the pressure release valve is closed tightly and with mounted protection cap
- Ensure the tether neatly coiled and connected to the computer system, PSU and ROV

ROV Safety Features

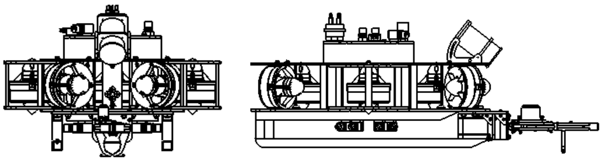
The ROV has a small positive buoyancy, enabling it to resurface under its own power in the event of power loss. The ROV has implemented leakage sensors in the bottom of the electric housing, signaling the co-pilot in the event of a leak. In the event of limbs being squeezed by the gripper, a safety release pin can be easily pulled out to release the gripper claws. Fuses are present on powerlines to the manipulator, preventing driver and DC-DC converters to burn out.

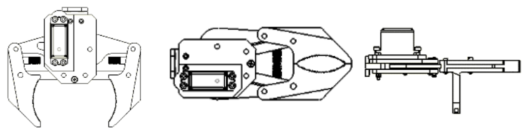
Figure 26 - Gripper safety pin

The Little Mermaid has encased thrusters, to provide minor protection from collision with objects. Due to a high current consumption of the thrusters, a current limiting algorithm has been implemented into the software, to ensure that the myRIO has sufficient power to control the thrusters. A strain relief is secured to the tether and mounted on the top end cap to prevent any stress on the tether cable.

Conclusion

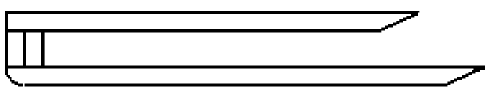
Specification sheet:





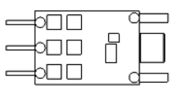
TOSCE ROV Specifications	Value	Unit
Length (without manipulator)	767 (550)	mm
Width	444	mm
Height, w.o. tether	296	mm
Weight, dry (with tether)	14.5 (20)	kg
Tether length	25	m
Depth rating	13	m
Ascend force, underwater (max)	200	N
Speed, vertical (no load)	1.8	m/s
Speed, ascend (no load)	2.5	m/s
Tilt angle (stable)	45	deg

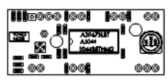
Electrical	Min.	Typ.	Max.	
Operation voltage DC	38	48	50.6	V
Current		22.5		A
Power consumption		1		kW
Fuse, main		35		A
V_{out} Gripper, clamp	2	7.2	16	V
A_{out} Gripper, clamp		2	4	A
Fuse, Gripper, clamp		2		A
V_{out} Gripper, rotation		16		V
A_{out} Gripper, rotation		0.68	2	A
Fuse, Gripper, rotation		2		A

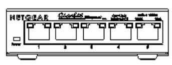


Sensor		
Temperature accuracy	0.5	°C
Pressure accuracy (depth)	30	mm

Tools		
Opening span, *grip.*	80	mm
Clamp force, *grip.*	8.7	N
Torque, *grip.*	0.7	Nm
Fork length, *stands*	480	mm
Fork opening distance, *stands*	40	mm
Fork tip load each (max), *stands*	50	N







Technical challenge

The two most significant challenges were waterproofing the camera canister cables and using FPGA to control the myRIO. The problem with waterproofing the cable for the camera was a breach at the part covering the soldering close to the connector for the main canister. The solution proved unable to withstand the strain and general wear from being bent, plugged and unplugged from the canister causing the water to travel from the breach and into the canister because of the pressure difference. To fix the problem and prevent it from happening three extra layers of shrinkable tubing coated with glue was used, filling the space between each layer with hot melt glue before shrinking the tubing.

FPGA became a problem because of the poor understanding of how to use FPGA combined with it having a steep learning curve. The problem was also discovered too late in the development cycle since the different parts of the code works independently and only fails to function when combined. It was necessary to use FPGA, since the myRIO by default only supplies eight ports for PWM signals and needing ten, one for each thruster and two for manipulator. To reduce the impact on available test runs that could be made and preventing it from influencing the time schedule, a second myRIO was used temporarily to run the two different sets of code separately. This allowed us to bypass the problem until a solution could be finished with minimal impact on the time schedule.

Interpersonal challenge

One of the most challenging aspects of this project was the lack of time, this resulted in a high workload. People have a tendency to make more mistakes when they are tired. One of the first wet runs ended catastrophically. Because of pilot's mental fatigue and an incomplete launch procedure, the ROV was launched with the top O-rings not seated correctly. The mistake was quickly spotted but it was too late. Water had entered the canister and 4 ESCs were water damaged. The troubleshooting and drying of parts delayed the project by a day. The launch procedure was quickly updated after these events.

Skills learned

During the project, the Company's members learned a lot about time management. The company quickly implemented Scrum to minimize time waste. Company members acquired a lot of technical knowledge over the duration of the project, including but not limited to: Underwater connections, chassis design/optimization, buoyancy, Software programming large scale, General electrics, leveling system and waterproofing canisters.

Final thoughts

This was the hardest challenges the group has ever faced time wise, however it is a fun and rewarding project to tackle. The company's members have really bonded over these past months and learned to respect each other's strengths and weaknesses. The Final product is a lightweight, small sized and agile ROV, ready to compete at the 2016 MATE ROV competition.

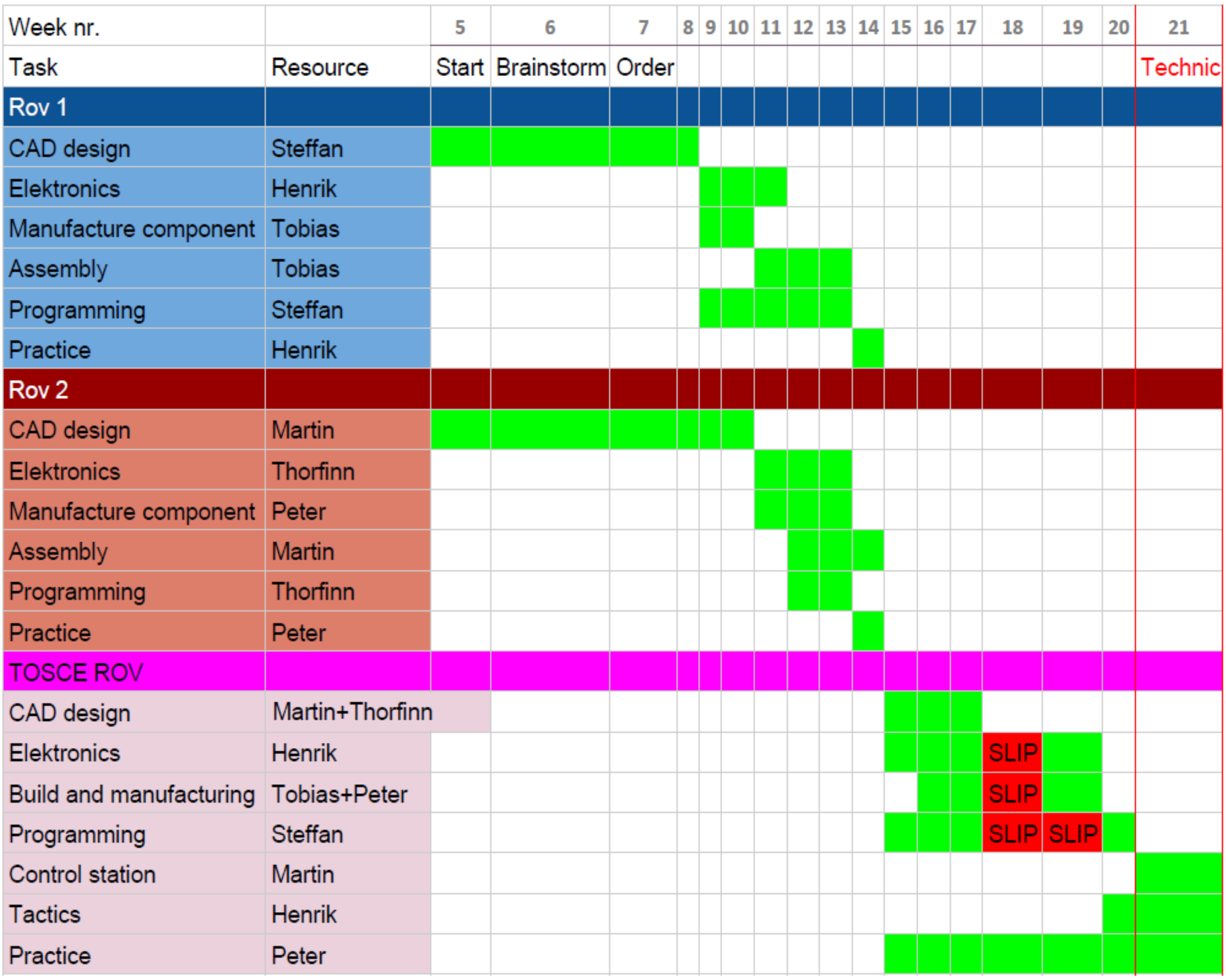
Litterature

The ROV Manual, Second Edition, Robert D. Christ, Robert L. Wernli, Sr., BH, 2014

Underwater Robotics – Science, Design & Fabrication, Steven W. More, Harry Bohm, Wickie Jensen, MATE Center, NSF

Appendices

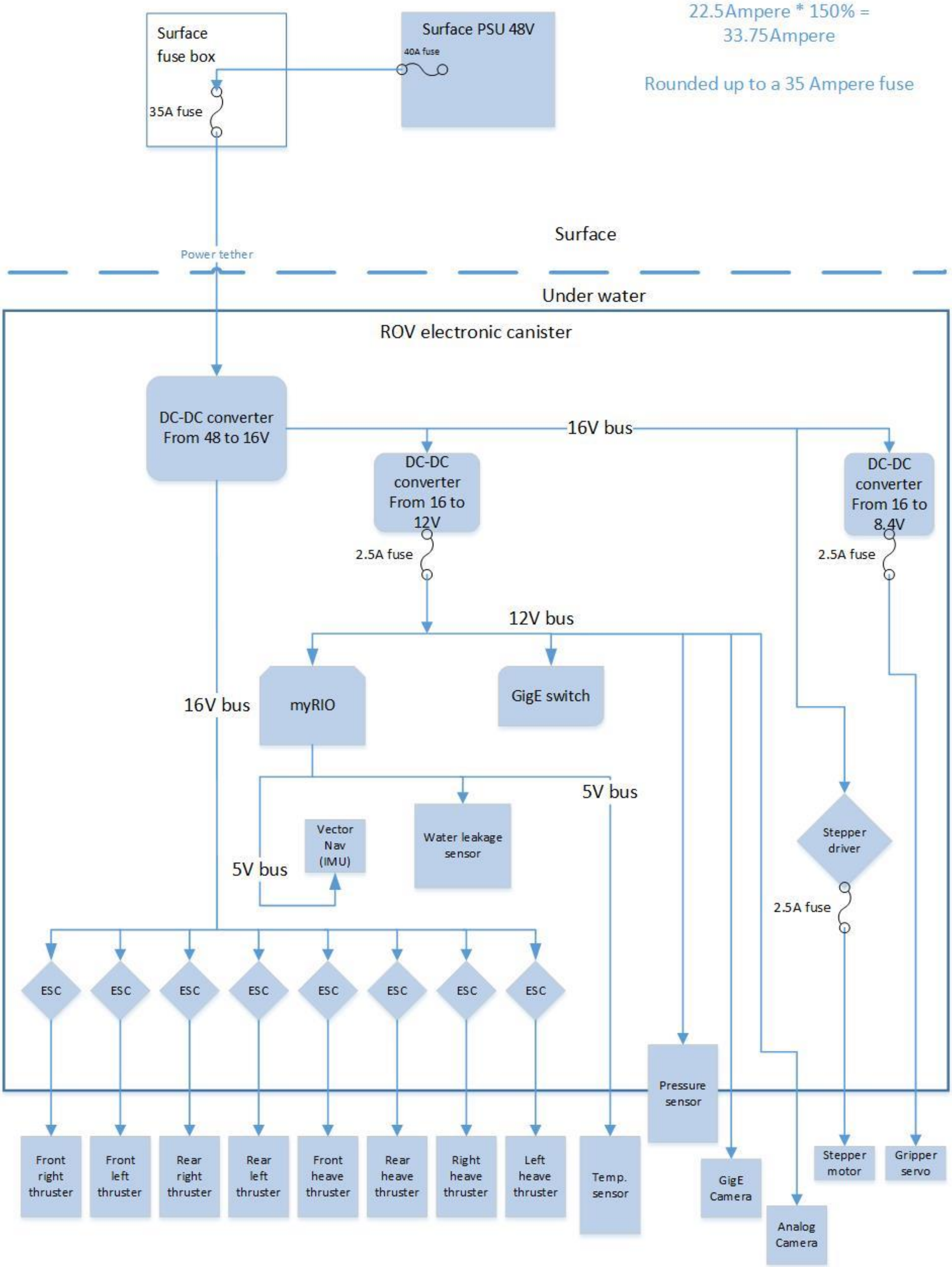
Schedule



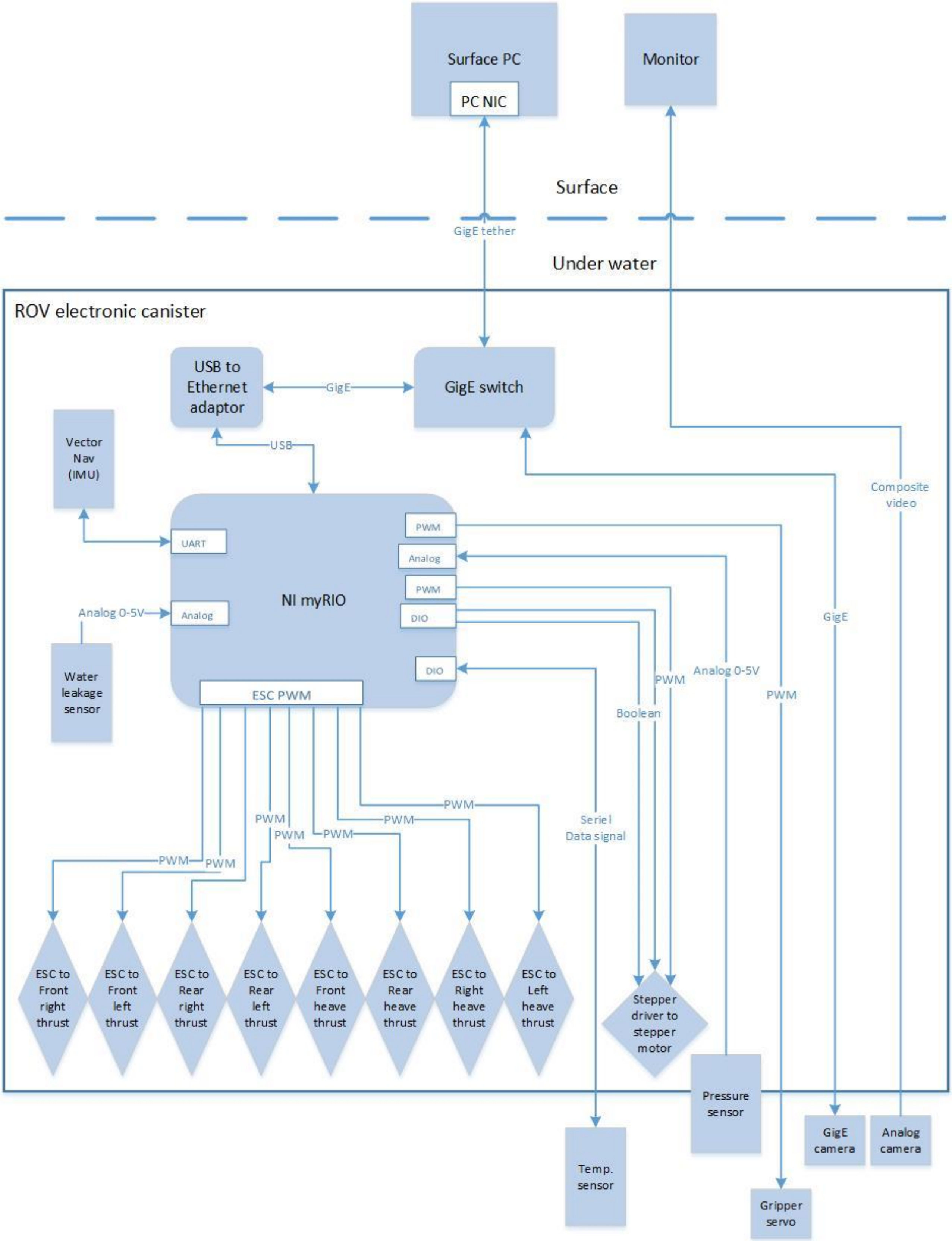
To complete the TOSCE ROV on time a Gantt chart was used by the Little Mermaids management. This was used to sync internal deadlines and keep track of resources.

Week 18 A problem with the ADC boards I2C communication with the myRIO caused the Electronics and Programming departments to miss their deadlines. This also delayed Build and manufacturing, because they needed to fix the problem before assembly could be completed.

A1: SID for power connections



A2: SID for communication connections



A3: Software Flowchart