VORTEX
NTNU

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1 Abstract

Vortex NTNU's newest Remotely Operated Vehicle(ROV), Manta, is developed to operate in both fresh and salt water areas in the Pacific Northwest. The rough environment requires a robust and reliable ROV that are modular and easy to handle. Manta is constructed and fully equipped to assist in a various missions, including but not limited to, wreckage location, subsea installation and heavy lifting.

Manta's core components are centered around a cylindrical aluminum housing with a transparent acrylic lid. The water tight enclosure is surrounded by a ABS body, consisting of a top and bottom frame, securely bolted together. Each of Manta's eight vectored thrusters are integrated into the polymer frame and are not vulnerable to accidental impact. In front, Manta has an acrylic dome containing an actuated camera with full vision ahead, and of the aluminum manipulator below. Manta's modular design supports five supplementary peripherals. To accomplish all the tasks specified we have equipped Manta with two extra camera's and mission specific tools.

Vortex NTNU, a company of 21, has throughout the development acquired essential organizational and technical skills by delivering a state-of-the-art product. Company members have dedicated over 8000 hours to fully meet the requirements specified in the Request of Proposals (RFP). The fair market materials value of Manta is 10000 USD. This technical document presents the process which resulted in our most complex vehicle yet.

Figure 1: Vortex NTNU – Team 2018

Contents

2 Design rationale

2.1 Design evolution

The next step in the Vortex design evolution began by addressing the strengths and weaknesses of the 2017 Terrapin design. A main success of this design was the easy access and visibility of electronic components.

With last year's ROV we faced difficulties with both the waterproofing and getting the buoyancy correct. A main focus of the 2018 design was to redesign the electronic house, keeping the positive features of access and visibility, but securing a more tight and robust design. Another design issue with Terrapin was the thruster placement outside the main frame, making them vulnerable to shock impact. Considering everything we have learned from previous years, have resulted in an improved design protecting the thrusters by integrating them into the ROV's body. The previous 6 DOF thruster layout with 8 thrusters at the vehicle's center of mass was kept, maintaining the maneuverability, speed and robustness of the Terrapin design.

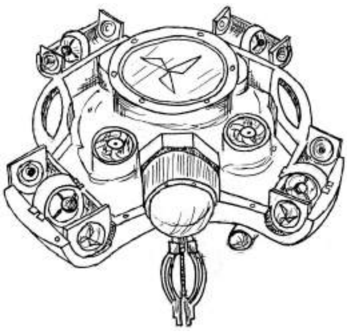


Figure 2: Conceptual design of Manta's inside

A major gamechanger in the 2018 design was the board's decision together with the main sponsor Equinor (formerly Statoil) to make an ROV capable of operating at 100 meters depth. This design constraint made the need for robust technical solutions even more important, resulting in a larger, heavier and a more costly design. As a result, the Blue Robotics T200 thrusters and camera enclosures was chosen over last year's self-made thrusters and camera sealing.

A shortcoming in the previous Terrapin electronics proved to be the relatively frail wire connections. This resulted in the design and assembly of custom PCB's as well as making the electronic system module based. The electronics design is one of the biggest improvements of the 2018 design increasing both robustness and serviceability of electronics. The software team has been another big focus area this year. The system code has been totally refurbished with the main focus of making it more user friendly. This includes the implementation of a startup file, easy readable GUI interface and an intuitive controller. Especially important was the development of a system that is plug and play even for a non team member. A pre-study of computer vision was also started aiming to solve the length measurements related to the Energy task and the image recognition task. Early on, extensive effort was put into the creation of a simulation platform making the team able to test the control system long before the completion of Manta herself.

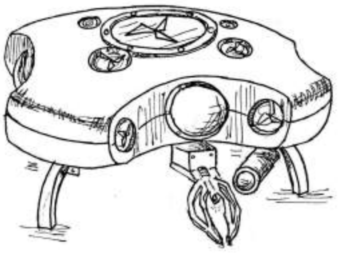


Figure 3: Conceptual design of Manta's exterior

2.2 Body

Manta's body consists of two parts tightened together with bolts. The upper part is easily removed making the thrusters, buoyancy foam and main camera easily accessible . On both port and starboard sides, handles have also been integrated, making it easier to launch and receive Manta. An important aspect of the body design was integrating the main equipment inside the body making the thrusters, cameras and cords less vulnerable to wear and tear as well as shock impact. The frame also protects humans from getting in contact with thrusters or potentially dangerous wires.

Being the superstructure of the ROV the frame required a stiff rigid body with high impact strength and with the lowest weight possible. ABS was selected over other polymers due to the strong impact resistance, high tensile strength and low cost. ABS has a low density of 1.060 g/cm3 making it a good choice with regards to buoyancy. Since the plastic body has been designed to keep the weight down, the body was coated with "raptor bedliner". This coating has great material properties which enhance both the strength of the body and increases the scratch resistance, and keeps a good finish in both chlorine and salt water. An important feature is the rails mounted underneath the body connecting the upper body with the payload. The rails make it easy to equip or remove equipment depending on the mission specific tasks.

Figure 4: Exploded view of Manta's major parts

The body was designed using CAD software and fabricated using CNC machining by an outside manufacturing service. An outside manufacturer was chosen due to the design being relatively complex making it very hard and time consuming machining it in-house. Another advantage was minimizing the time spent in production, increasing the time for test and verification.

2.3 Buoyancy

In order to compensate for the weight of frame, manipulators and electronic components a buoyancy foam was installed in the top part of the frame. The buoyancy needed was calculated by Archimedes' principle using pre-calculated data from CAD software. The foam used was the Divincell H 130 with compressive strength for depths down to 300 meters. A weaker foam could have been chosen, but the H 130 adds a safety margin of 150 % with only a slight increase in the nominal density making it an ideal choice.

2.4 Thrusters

Manta is powered by eight T200 brushless thrusters from Blue Robotics. Blue Robotics thrusters was chosen due to their excellent reliability, durability and ability to operate at high pressure. The T200 model was chosen specifically due to a sponsorship deal with a local

ROV manufacturer Blueye Robotics. Four vertical thrusters are placed in a perfect square with the horizontal thrusters placed outside in a similar square, only rotated 45 degrees.

The design is specifically designed to make Manta move in any direction with 6 degrees of freedom. Following last year's success by mounting all thrusters in a plane at roughly the same height as the vehicle's center of mass (COM), unwanted rotations is avoided when moving in straight lines making Manta easier to control. Manta's improved stability also avoids unnecessary compensation by the control system thus saving energy. The horizontal thrusters was mounted with an angle of 45 degrees giving higher sideways speed at the expense of forward speed (30 degrees mounting) mostly due to a symmetric design being more visually beautiful. Also due to the T200 thruster being extremely powerful, full thrust is never necessary, making it less important to prioritize one velocity direction over another.

Figure 5: Bird's-eye view showing the thruster layout

2.5 Electrical Housing

This year, one of our main concerns from a hardware point of view, has been creating a very durable and robust design. Naturally this has also been an important design parameter for the electrical housing, which contains most of the subsea electronics.

The pressure rating for our ROV; Manta, is set to 100 meters of water depth, or approximately 10 bars of pressure. Being able to withstand these water depths have made the design more challenging, adding to the already complex demand of creating a housing suited for all our electronics, as well as making it fit together with the rest of the ROV's body. The main housing is machined out of a single, large piece of aluminum 6082 T6, which has then been anodized with a red dye, both for corrosion resistance and design purposes.

The main seal is a large Parker O-ring fitted in a customized O-ring groove in the top flange for the housing, sealing against the acrylic lid. The lid is being secured to the housing via 6 bolts, M6 A4 with tapered heads. We have also created a bottom plate which is lowered into the housing and has all the holes for fastening the electronics. This plate is an important part of the design, as it both works as the fastener for the pressure sensor and our vacuum test plug. The main reason for using the bottom plate together with the vacuum plug and pressure sensor is to be able to test the vacuum and change the vacuum test plug with a blind plug without having to opening the housing to hold a nut. It also provides additional flexibility, since we can redesign all of our electronics layout without having to create a whole new housing, only needing the bottom plate redesigned. The use of this plate also substantially simplified the machining of the electrical housing. All cables going in and out of the housing are sealed using Pflitsch Blueglobe cable glands, IP 68 rated, up to 15 bar. A rather quick assembly with no need for potting. In designing the housing, we have used Inventor professional for all our 3D mechanical design. We have also used their FEA simulation tools for optimizing our design. Mechanical drawings of the electrical housing and the bottom plate are available in appendix A.

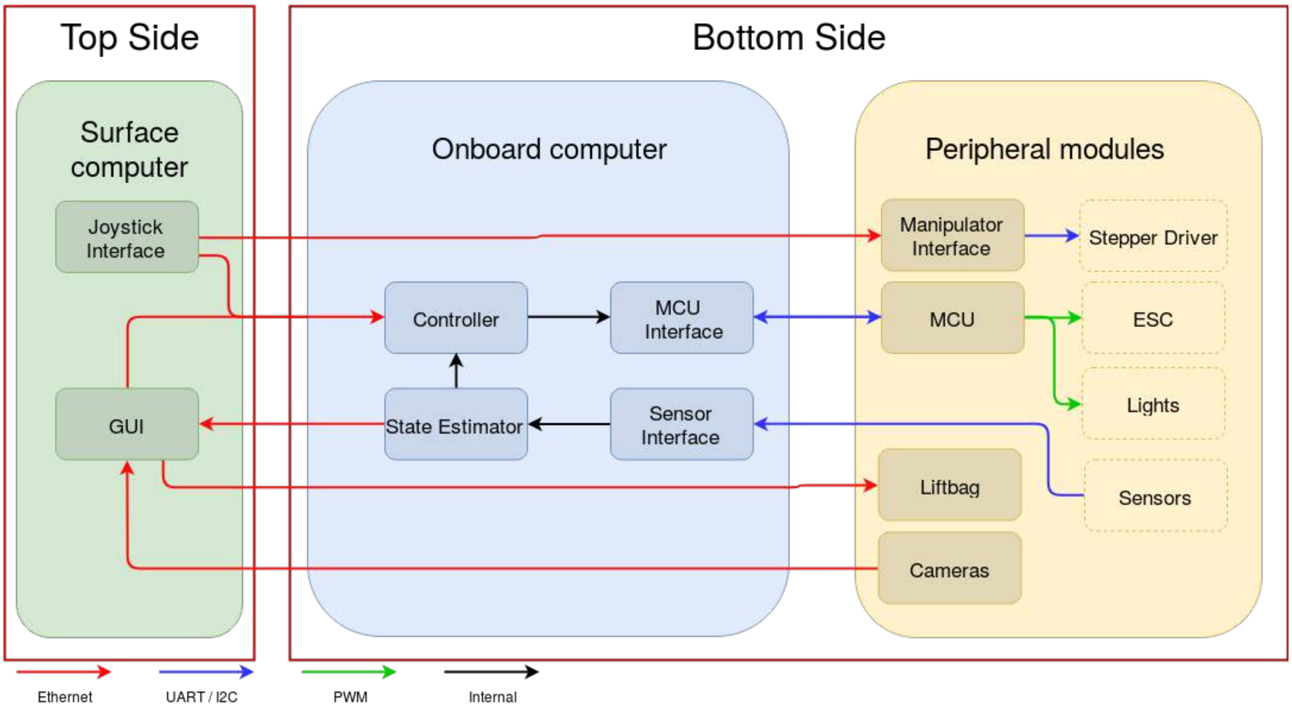


Figure 6: Software block diagram

2.6 Software

Figure 6 gives an overview of the software employed on the ROV. The core of the software system is implemented on the bottom side on an Odroid XU4, which acts as Manta's Onboard Computer (OBC). The OBC runs the control system and interfaces to a number of peripheral modules each with a specific responsibility. Each module is implemented on an designated computer. The manipulator interface, liftbag and camera module is each implemented on Nano Pi's, a small sized Single Board Computer (SBC) and the microcontroller (MCU) module utilizes an EFM32 Giant Gecko chip. All control software on Manta is written in-house in C++ and Python using the Robot Operating System (ROS) framework. All of the computers peripheral computers communicates with the ROS framework over Ethernet. Other languages and tools that are used are gstreamer for camera feed, bash scripting, and other OS dependent tools on the SBC's and a bare-metal C program on the MCU.

2.6.1 Robot Operating System (ROS)

One of the reasons for choosing ROS as framework, was the possibility of using many of the libraries provided, such as the tf library used to in Manta's controller. Secondly, ROS is a modular framework, meaning that one can reduce the complexity of the system by dividing it into "nodes". Each node has a specific role within the system, and is thereby encapsulated. The main advantage of such encapsulation, is reducing complexity when both maintaining nodes and developing new ones, as this does not affect the system as a whole. The communication between the nodes is done using "messages". The messages are sent asynchronously from the publisher to the subscribers, through logical channels which are called "topics". Topics is able to be sent over a network which means that the nodes of an ROS system is not limited to running on a single computer. This makes the interfacing between computer easy. In addition ROS provides an interface to the Simulator tool Gazebo and made the development of an simulator easier.

2.6.2 Graphical User Interface

This year's GUI was made with React, a JavaScript framework for building web-applications. The GUI communicates with Manta by sending and receiving ROS-messages over WebSocket to the WebSocket-server running on the ROV. The GUI can be used from a web-browser, but with the Electron-framework it can easily be packaged into an executable desktop application (as can be seen in fig. 7), which is how the GUI will be used for this year's competition.

There are several reasons for why a web-application was chosen. First of all, portability will in general never be an issue. As long as there exists a web-browser for the chosen platform, the GUI will work. The GUI being a web-application also enables it to be used from wherever you want. The GUI could in theory be used from the other side of the world by just opening a website. One final advantage of a web-application is the vast ecosystem of libraries accessible for web-applications, which increases productivity immensely.

There are several sub-pages of the interface for dealing with certain mission specific tasks, screenshots of these are shown in section 2.10.

Connecting to ROS-bridge...

Figure 7: The loading screen displayed while attempting to connect to the ROV

2.6.3 Simulator

A simulator of Manta was developed this year. Gazebo is used to set up a simulated underwater environment where a model of Manta is spawned. This model is directly controlled by Vortex' control system. The control system applies thruster forces on the simulated Manta equivalent to the forces it would apply to the real Manta.

The simulator enabled testing of the control system alongside with the design and production of Manta. Gazebo also provides plugins that can simulate a camera feed from the simulated environment. With the simulated camera feed it is possible for the pilot to train maneuvering Manta as well as test the computer vision tasks. A screen grab from the system is shown in fig. 8, where the ROV camera feed is displayed in the left part of the image, and an overview to the right.

The challenge of making the simulator was to model the environmental forces that water apply to submerged objects. This was done by a simple approximation by applying dampening forces proportional to the speed and rotation squared. The simulator also requires a precise configuration of physical parameters to get a precise representation of the behaviour of Manta.

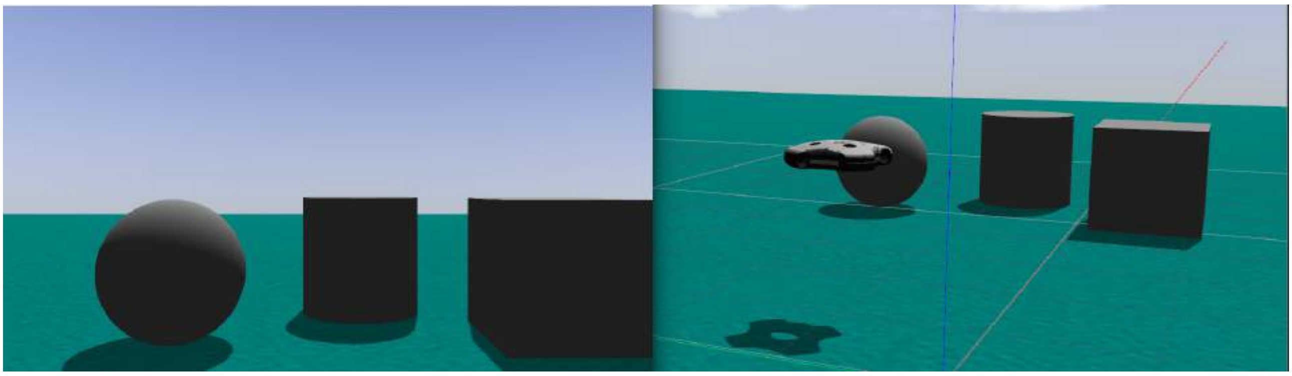


Figure 8: Screengrab from the simulator

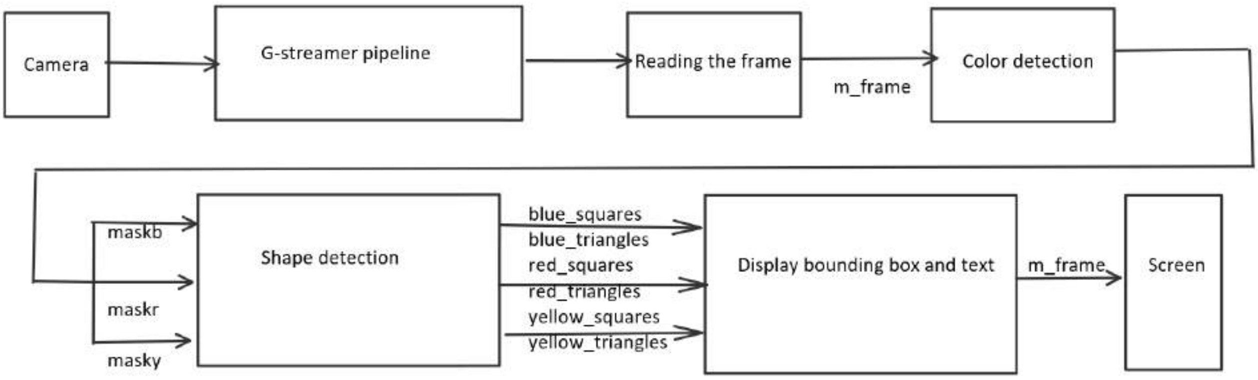


Figure 9: Flowchart of the computer vision system

2.6.4 Computer Vision

In order to identify the aircraft the ROV need to be able to distinguish between the different models. The problem is tackled using algorithm for color detection and shape detection. The flowchart of the algorithm can be seen in fig. 9. The algorithm uses functions from the open source library OpenCV.

The first step is to convert the image to three mask images, one blue, one red and one yellow. These mask images are binary images with the pixel value 1 if the color is within the specified bounds, if the pixel is outside the bounds it has the value 0. The algorithm operates in the HSV, Hue Saturation Values, color representation. In the flowchart there are two blocks where the algorithm sorts based on indicated upper and lower values. The first sorting is based on the area of the identified contour in order to discard small contours. The second bases the sorting on the circularity value of the contour to determine if it is a triangle or a square. At the end we display all triangles or squares found in their respective mask image.

2.7 Electrical Systems

Our key goals when designing Mantas electronics system was modularity and great serviceablity. Two new innovations have helped achieve these goals.

The first is a modular backplane built around a big 28 pin power and communications buss.

Four identical slots for PCB cards are connected to this main buss. This allows us to move the electronics around or add new functionality when needed. Two of the moduluar slots are used to build the core ROV system. One card for the on-board Linux computer which runs the control system. Time sensitive tasks such as controlling thrusters, detecting leaks and controlling headlights is handled by a micro controller card. This leaves two slots open for future functionality or additional computation modules. The modular slot solution also lowers production cost by allowing us to reuse modules on later projects.

Power electronics are mounted to the bottom plate of the aluminum electronics enclosure. This provides excellent cooling for the motor controllers and the DC-DC step down converter.

Signal cables are all routed through the properly shielded backplane. This separates the power electronics on Manta's bottom layer from the sensitive electronics at the top of the electronics stack.

Mantas second big innovation is a standardized modular peripherals system. We have standardized all of our peripherals with the same interface; 100 Mbps Ethernet for communication and 12 VDC for power. We use the same type of cable for all peripherals: 4 twisted pairs, two pairs for communication and the remaining two for power.

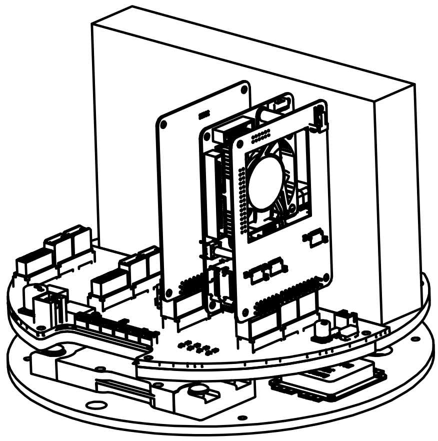


Figure 10: Drawing of the electronics in Manta

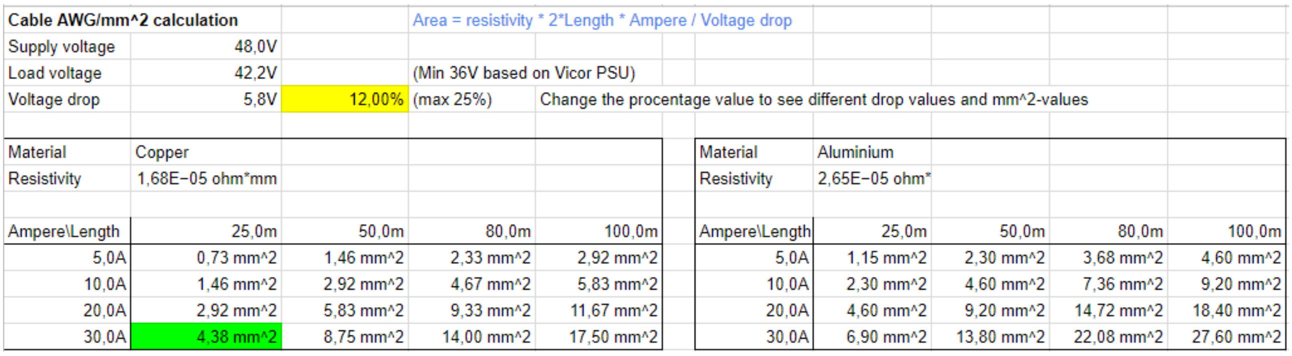
All of Mantas peripherals are standalone modules that have a dedicated NanoPi Neo plus 2 for communications with the main computer. Having a dedicated computer for each peripheral module (cameras, manipulators, etc) is essential for making Manta modular. It enables us to do changes in the peripheral modules without having to change, or even open the main electronics enclosure.

Peripheral communications go through our 8-port Gigabit ethernet switch. The switch is connected to the topside unit through our tether.

2.8 Tether

The tether we are using for mate is made up of three individual lines; one for power, one for communications and one for pneumatics. The Power line is a cable with four 2.5 mm^2 cores, where we use two for 48 VDC and two for ground. This is within our requirements from our calculations given in fig. 11. As two of our 2.5 mm^2 equals 5 mm^2.

The communication cable is a cable with 8 cores, configured as 4 twisted pairs, this cable is neutral buoyant in water and can achieve data rates up to 1 Gb/s. The pneumatic line is a simple silicone hose which runs along the tether and continues underneath the rov and ends with the manipulator, so that it can fill the lift-bag while visible from the main camera. All the lines are combined as one line using a flexible sleeve. The tether will furthermore be made neutral in water by using buoyancy elements.



Cable AWG/mm^2 calculation			Area = resistivity * 2*Length * Ampere / Voltage drop	
Supply voltage	48,0V			
Load voltage	42,2V		(Min 36V based on Vicor PSU)	
Voltage drop	5,8V	12,00%	(max 25%)	Change the procentage value to see different drop values and mm^2-values

Material	Copper			
Resistivity	1,68E−05 ohm*mm			
Ampere\Length	25,0m	50,0m	80,0m	100,0m
5,0A	0,73 mm^2	1,46 mm^2	2,33 mm^2	2,92 mm^2
10,0A	1,46 mm^2	2,92 mm^2	4,67 mm^2	5,83 mm^2
20,0A	2,92 mm^2	5,83 mm^2	9,33 mm^2	11,67 mm^2
30,0A	4,38 mm^2	8,75 mm^2	14,00 mm^2	17,50 mm^2

Material	Aluminium			
Resistivity	2,65E−05 ohm*			
Ampere\Length	25,0m	50,0m	80,0m	100,0m
5,0A	1,15 mm^2	2,30 mm^2	3,68 mm^2	4,60 mm^2
10,0A	2,30 mm^2	4,60 mm^2	7,36 mm^2	9,20 mm^2
20,0A	4,60 mm^2	9,20 mm^2	14,72 mm^2	18,40 mm^2
30,0A	6,90 mm^2	13,80 mm^2	22,08 mm^2	27,60 mm^2

Figure 11: Tether calculations

2.9 Sensors

There are two main sensor systems on Manta. They are used for providing a position estimate and detecting leaks.

To provide a position estimate Manta uses a 9 - degrees of freedom inertial measurement unit (IMU). A magnetometer, accelerometer and gyroscope provide the IMU with three degrees of freedom each. Our on board computer communicates with the IMU using I2C. The on board computer runs a sensor fusion algorithm to negate gyro drift and other inaccuracies in the IMU. We utilize the open source madgwick sensor fusion algorithm, and it has proven remarkably robust. The IMU has also been improved by adding an on chip memory module, this is to simplify the process of storing and uploading calibration data.

Depth sensing is done via the Blue Robotics Bar30 pressure sensor.

The position estimates provided by the pressure sensor and IMU are currently being used to implement two control modes. Heading hold and depth hold. The control modes have proven effective at eliminating disturbances from the tether when doing object manipulation on the seafloor.

New this year, is a tightly integrated leak detection system. When a leak is detected in the electronics compartment the motor controllers are automatically disarmed and a warning is issued to the operator. By disarming the thrusters automatically upon detection of a leak, the damage to the on board electronics are minimized.

2.10 Payload and mission specific features

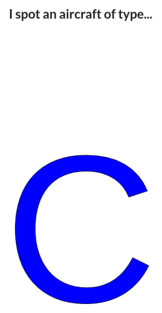
The team wanted to improve both the manipulator and the motorhousing with emphasis on robustness since there were several issues regarding both waterproofing and manipulator movement last year. This year's ROV, Manta, uses a gripper with just one degree of freedom, but with the opportunity to attach tools to gain flexibility if needed. For the earthquake task a rotator working around the z-axis was also designed in order to rotate the four PVC tee's. The gripper and rotator is driven by one 12V stepper motor each. These motors were chosen because they are relatively simple and have a good holding torque. Due to the waterproofing issues last year, the team decided to develop a new housing for the motors.

Figure 12: The tool made for leveling the OBS

Both the housing and manipulators were designed in a 3D CAD software, 3D printed in polylactic acid (PLA), thoroughly tested and then finally made of aluminium T6. This reduced the possibility of malfunctioning and made the overall manipulator system more robust with tighter joints.

With the help of the designated rails on the ROV, both the housing and manipulators were attached with high flexibility to move both the gripper and rotator if needed.

For the Earthquake-task a GUI-tab displaying live data received from Manta was made (see fig. 16). The OBS-angles are displayed inside a virtual bubble-level. The seismographic data received from the OBS is also displayed as per MATE's specifications. For the aircraft-identification task, a simple tab displaying the type of aircraft detected was made (see fig. 13). The search-zone location task is made easy by a simple input-form (see fig. 17), minimizing the chance of human error.



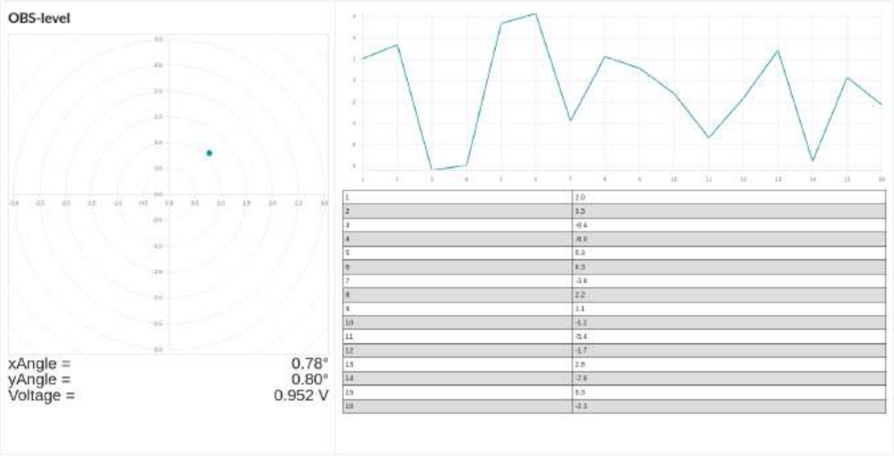
I spot an aircraft of type...

C

Figure 13: The GUI-tab for detecting different aircraft types

Figure 14: 3D-printed prototype of the manipulator

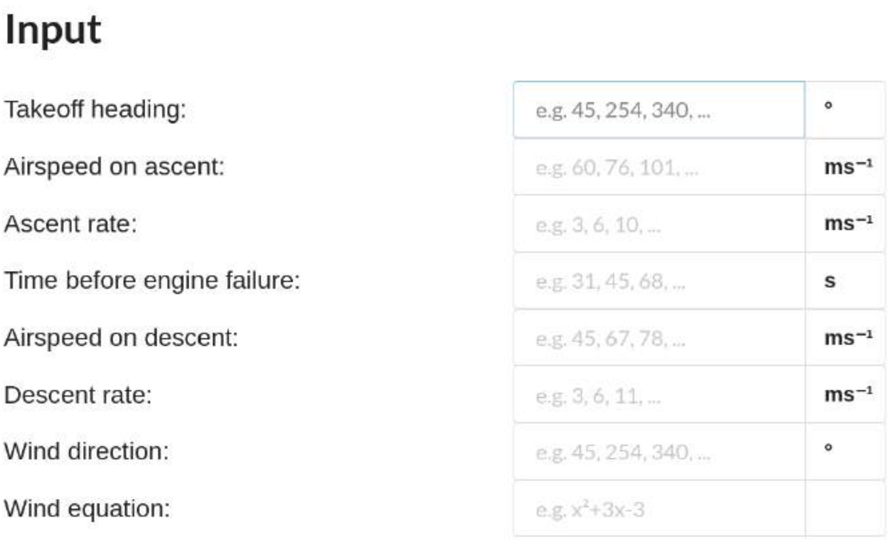
Figure 15: Finished manipulator manufactured in aluminium



xAngle = 0.78°
yAngle = 0.80°
Voltage = 0.952 V

1	2.0
2	3.3
3	-8.4
4	-8.0
5	5.3
6	6.3
7	-3.6
8	2.2
9	1.1
10	-1.2
11	-5.4
12	-1.7
13	2.8
14	-7.6
15	0.3
16	-2.3

Figure 16: GUI-tab for displaying OBS-data



Input

Takeoff heading:	e.g. 45, 254, 340, ...	°
Airspeed on ascent:	e.g. 60, 76, 101, ...	ms⁻¹
Ascent rate:	e.g. 3, 6, 10, ...	ms⁻¹
Time before engine failure:	e.g. 31, 45, 68, ...	s
Airspeed on descent:	e.g. 45, 67, 78, ...	ms⁻¹
Descent rate:	e.g. 3, 6, 11, ...	ms⁻¹
Wind direction:	e.g. 45, 254, 340, ...	°
Wind equation:	e.g. x^2+3x-3	

Figure 17: GUI-tab for calculating aircraft search zone

3 Safety

3.1 Safety philosophy

Safety in all our work and actions is a primary focus for Vortex. We believe that all accidents can be prevented, and we therefore strive to offer a safe work environment for all our employees. A comprehensive safety policy through procedures, protocols and thorough training facilitates avoidance of accidents preemptively.

3.2 Lab protocols and training

The lab facilities our company employees utilize are regulated by the Laboratory and Workshop Handbook elaborated by the HSE division of NTNU. Other work areas dedicated to performing risky operations have lab protocols elaborated and supervised by the company's respective technical lead. All our employees must at all times be aware of the guidelines associated with the facilities. Our seniors review and ensure that new members are given rigorous training instructions on safety practices such as electrical safety, tool safety, workshop tidiness, and handling of hazardous materials.

3.3 Vehicle safety features

Manta is designed with regards to keeping the crew, ROV, and work environment safe during operation. The electronics housing is waterproofed through well tested methods to protect the components from water exposure. In case of water leakage, Manta contains a leak sensor, which automatically disarm the thrusters and notify the operator.

At each side of the body Manta has sturdy handles. This makes launch and retrieval a lot safer and the ROV is easier to handle in every situation. Other safety measures include status LED indicators, easily inspectable through the transparent lid, fuses on all high voltage lines to prevent accidental short circuit and a kill switch implemented in the GUI and physically on the control box. Adequate warning labels are included on power connections and rotating parts.

We have put extensive effort into the safety and reliability of the software. Each node automatically checks all incoming communication, and discards any invalid data so that it does not propagate further in the system and cause harm. All nodes are designed to shut down gracefully in case of fatal errors, without affecting the other parts of the system.

3.4 Operational safety practices

The operational Job Safety Analysis (JSA) was developed by a group composed of new, as well as senior employees, of last years team. The current team still agrees with the practices proposed earlier, and therefore we see no reason to alter the JSA.

The content of the JSA is based on a toolbox talk. This discussion lays the foundation for a broad understanding of potential hazards as well as encouraging our employees to work more effectively and safely. All members are also encouraged to update safety protocol whenever a dangerous situation arises, to ensure that the same situation does not occur in the future. The operational JSA is used to ensure safe deployment, handling and recovery of Manta.

4 Logistics

4.1 Project Management

Vortex NTNU is composed of four departments; mechanical, electrical, software and marketing. Each of the technical departments has a department lead who reports directly to the CTO, a new role in the company. The CTO's main task is to ensure exceptional cooperation between the technical departments and communicate the technical progress to the rest of the management. In addition to the main departments, we assigned smaller task forces to the tasks that benefit from closer collaboration between members of different departments, including; camera, liftbag, manipulator and topside unit. These task forces created a great multidisciplinary learning environment for our members.

The management structure of Vortex necessitates the use of modern collaboration tools. Tasks are assigned and tracked through the online task planner OpenProject, making it easy to track the progress, history and involved staff for any task, as well as managing deadlines. For day-to-day communications, Vortex has adopted the team communication platform, Slack, which offers instant messaging and chat rooms, allowing all Vortex communication to happen on a single official platform, rather than leaving each group to their own incompatible platforms. Finally, Vortex employs the version control system git to maintain the source-code for the software systems as well as tracking software specific tasks not relevant for the rest of Vortex.

4.2 Scheduling

Early October, the management of Vortex NTNU created the simple Gantt chart in fig. 18, of the main processes throughout the project. Later, this plan got integrated with OpenProject with additional detailed information on subtasks, deadlines and employees responsible.

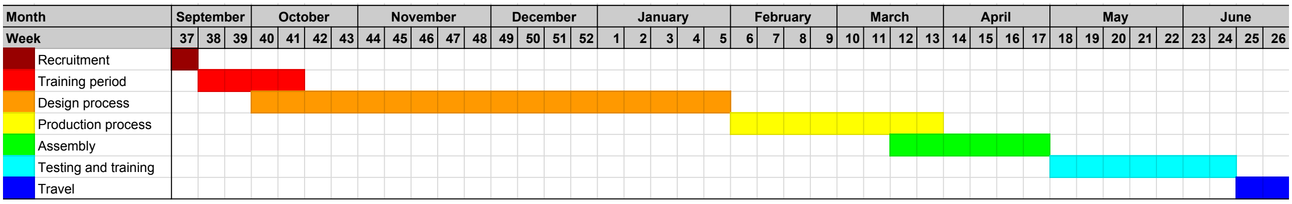


Figure 18: Gantt chart of main project processes

To ensure the progress and quality of our work, the management held two weekly meetings; one technical and one administrative. To have two meetings instead of one was a new idea this year, and a very successful one. This meant that we had time to dive deeper into the technical discussions, without affecting the time dedicated to discuss organizational problems, and vice versa.

Figure 19: One of the monthly design reviews

In addition to meetings, we organized monthly design reviews. At these events, each department presented some of their progress, difficulties and plans ahead. Here, every team member could get a overview of what everyone was working on, indulge in the same challenging problems and influence the overall project further.

4.3 Project Costing and Budget

Vortex NTNU's budget for this year's project was created early in September 2017 in NOK. The budget was based on the actual costs and income of the 2016-17 team. The budget was originally split into six separate budgets. These budgets were Electronic, Control, Mechanical, Marketing, Administration and Travel. These preliminary budgets made no distinction between "needs", "wants" and "nice to haves". This was done because the level of income was unknown, for instance there was a high degree of uncertainty with regards to how large the travel expenses would be.

The budgets for Electronic, Control and Mechanical were later revised. These separate budgets were merged to create the production budget, which was the expected fair market value of Manta. The Marketing and Administration budgets were also merged and became the organizational expenses budget, while the travel expenses budget remained separate. A table of incurred costs, budgeted costs, income and budgeted income is presented below in USD. The conversion rate used is 1 NOK = 0.125 USD, which is a rough average of the currency at the time of procurement.

Note that the electrical components and mechanical materials were cheaper than budgeted. The machining and painting of the hull became much more expensive than budgeted. Operational expenses exceeded what we expected since we acquired a soldering station.

5 Conclusion

5.1 Testing and Troubleshooting

Throughout this project the mechanical team has been remarkably thorough with testing their designs before production. Through Finite Element Analysis and 3D printing of all important details they have avoided numerous potential errors.

When electrical department finished soldering the PCB's, testing them became our primary focus. We had to find any detrimental errors, in case we had to order replacement boards. Testing the boards was a rigorous joint team effort. After separate unit tests integration tests of the assembled system was done. The test was deemed a success after several hours of nominally performance.

5.2 Challenges

Early in the project we opted to release our liftbag using WiFi communication. Transmitting wifi signals through water was a major technical challenge. After testing a variety of different WiFi modules, antennas and enclosures, we went from an inadequate range of about 3-5

Table 1: Project costing and budget

Vortex NTNU 2018 Expenses and Budget [USD]					
Budget Category	Item and Description	Type	Amount	Total Amount	Budget Allocated
Electrical: Boards	PCB Printing	Purchased	$240.00	$240.00	$375.00
Electrical: Components	Components for Board Population	Purchased	$128.00	$2,552.31	$4,625.00
	Tether Creation Material (Wires, Ethernet Cable, etc.)	Purchased	$107.38		
	Tethers	Purchased	$328.09		
	Cameras	Purchased	$272.83		
	Stepper Motors	Purchased	$28.21		
	Nanopi	Purchased	$236.44		
	Odroid	Purchased	$62.50		
	Odroid Connector	Purchased	$22.00		
	SD Card	Purchased	$12.50		
	Lumen Subsea Light	Purchased	$203.35		
	Pressure Sensor	Purchased	$69.49		
	IMU	Purchased	$87.49		
	ESC	Purchased	$419.04		
	Cords	Purchased	$107.38		
	DC DC Converter	Purchased	$417.63		
	Switch	Purchased	$50.00		
Mechanical: Machining	Machining of Hull	Purchased	$3,645.00	$3,645.00	$2,875.00
Mechanical: Paint	Painting of Hull	Purchased	$532.88	$532.88	$0.00
Mechanical: Materials	Aluminum End Caps	Purchased	$132.70	$1,711.31	$2,000.00
	Acrylic Tube	Purchased	$40.87		
	O-Rings	Purchased	$28.01		
	O-Ring Flanges	Purchased	$105.63		
	Pinboard	Purchased	$24.75		
	Plastic Plates	Purchased	$70.63		
	Vacuum plugs	Purchased	$16.35		
	Aluminum Profiles	Purchased	$193.75		
	Materials for Electrical Housing	Purchased	$468.75		
	Screws	Purchased	$37.50		
	Miscellaneous	Purchased	$331.25		
	Penetrators	Purchased	$146.00		
	Prototyping 3D PLA	Purchased	$115.13		
Total Expenses for ROV Construction				**$8,681.50**	**$9,875.00**
Fair Market Value (incl. Donations)				**$10,033.50**	**-**
Pelicase assembly components	Pelicase	Purchased	$58.96	$58.96	$625.00
Marketing Expenses	Clothing, hoodies and t-shirts	Purchased	$2,580.00	$2,872.71	$3,750.00
	Rollups	Purchased	$195.16		
	Posters	Purchased	$73.81		
	Web	Purchased	$23.75		
Operational Expenses	Team Building	Purchased	$756.80	$4,739.10	$3,500.00
	Tools and equipment	Purchased	$2,946.24		
	Props	Purchased	$304.65		
	Coffee, cups, etc.	Purchased	$407.50		
	Bank fees	Purchased	$131.42		
	Miscellaneous	Purchased	$192.50		
Total Organizational Expenses Vortex NTNU				**$7,611.82**	**$7,875.00**
Mate Travel Expenses	MATE Registration Fee	Purchased	$315.02	$5,083.54	$18,750.00
	ROV Transport Expenses	Purchased	$800.00		
	Team Transport in Seattle	Purchased	$1,200.00		
	Vortex NTNU cover of Flight Expenses	Purchased	$0.00		
	Air BnB	Purchased	$3,568.52		
	Special Baggage and Miscellaneous	Purchased	N/A		
Total MATE Travel Expenses				**$5,083.54**	**$18,750.00**
Donations	T200 Bluerobotics Thrusters	Donated	$1,352.00	-	$1,125.00
	Laptop Computer	Donated	$125.00	-	$750.00
	Computer Screens	Donated	$250.00	-	$125.00
	Water Linked acoustic positioning system	Donated	$5,500.00	-	-
Cash income (sponsorship)	Department of Engineering Cybernetics, NTNU	Cash	$7,500.00	$35,500.00	$38,500.00
	Statoil ASA	Cash	$25,000.00		
	FFU	Cash	$3,000.00		
Total Income				**$32,500.00**	**$38,500.00**
Total Expenses				**$21,376.85**	**$38,500.00**

cm to a somewhat stable range of 20 cm. We are still not satisfied with the range but with a thoughtful placement of the module we are pleased with the performance.

5.3 Lessons learned

Last year, the lack of a proper project planning and management tool was an Achilles' heel for the project, which made it difficult to track different tasks and coordinating efforts. We have therefore integrated the use of OpenProject in our routines. By tracking metrics such as track completion, and having clearly defined goals and specifications the company is able to both get a better overview of the project, as well as gaining vital information for improving and evaluating our next project. The usefulness of a tool like OpenProject, has been a valuable lesson this year.

Another valuable lesson we have learned this year, is to document everything thoroughly. The previous years, the documentation within the company has been lacking so this year we decided to create our own wiki page. With this wiki page we are able to transfer previous experiences, and competence very efficient.

5.4 Future improvements

In the future we want to improve the modular design of Manta to also include the connection points for the peripheral units. We had a hard time finding suitable connectors for this purpose, so currently, the peripheral systems is using cable glands. This is the bottle neck that makes the assembly process time consuming and challenging. With the future transition to dry connectors for the power and communication to peripherals, we will hopefully reach the high level of modularity we strive for.

This is the first year we use leak sensors inside the electrical housing. The extra chip and wiring to the leak sensor probes makes the interior observably less organized. An improvement would be to integrate leak detection circuitry in all of our circuit boards including peripheral modules to have complete control of leaks. This will not just make the electronics enclosure more organized, it will allow us to pinpoint the exact locations of potential leaks.

6 Acknowledgements

Vortex NTNU would like to thank the following contributors for their support and guidance in the development and production of Manta, and making our journey to the 2018 MATE international ROV competition possible:

MATE Center and Marine Technology Society: For hosting this year's competition

Statoil AS: Our main collaborator. Funding most of our components, and technical guidance.

NTNU Institute of cybernetics: Providing offices, lab and workshop areas. Funding of lab equipment, components and pool facilities.

Water Linked AS: Supporting us with one of their acoustic SBL systems, enabling precise positioning of Manta as far as 100 meters away in any direction.

FFU: Financial support and the opportunity to write for Norway's largest news magazine for subsea technology and underwater robotics, DYP.

Blueye AS: Providing us with Blue Robotics T200 thrusters and valuable knowledge in ROV development.

7 References

NTNU, HSE Department. Laboratory and Workshop Handbook. Trondheim: Fagtrykk Trondheim AS, 2016.

A Mechanical drawings

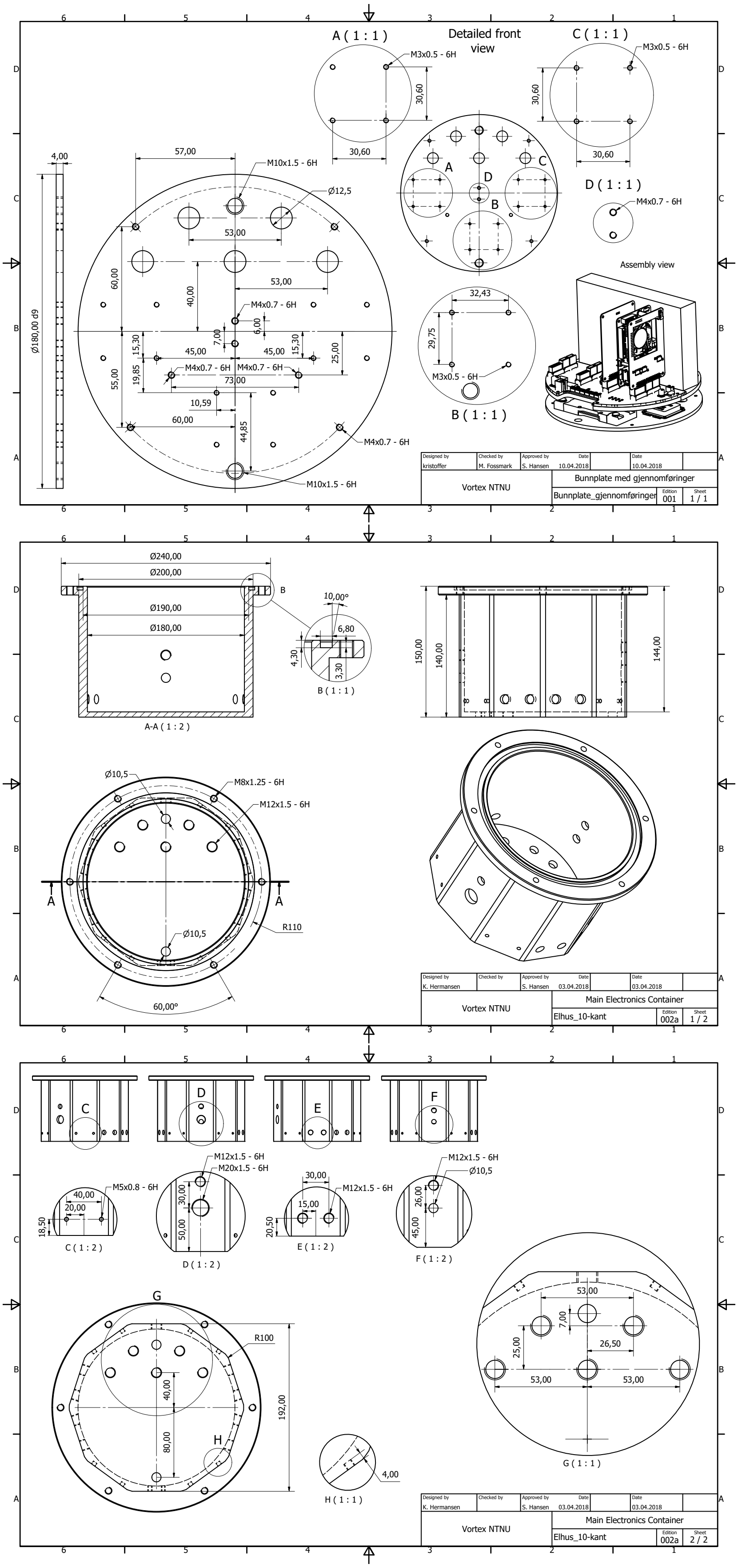
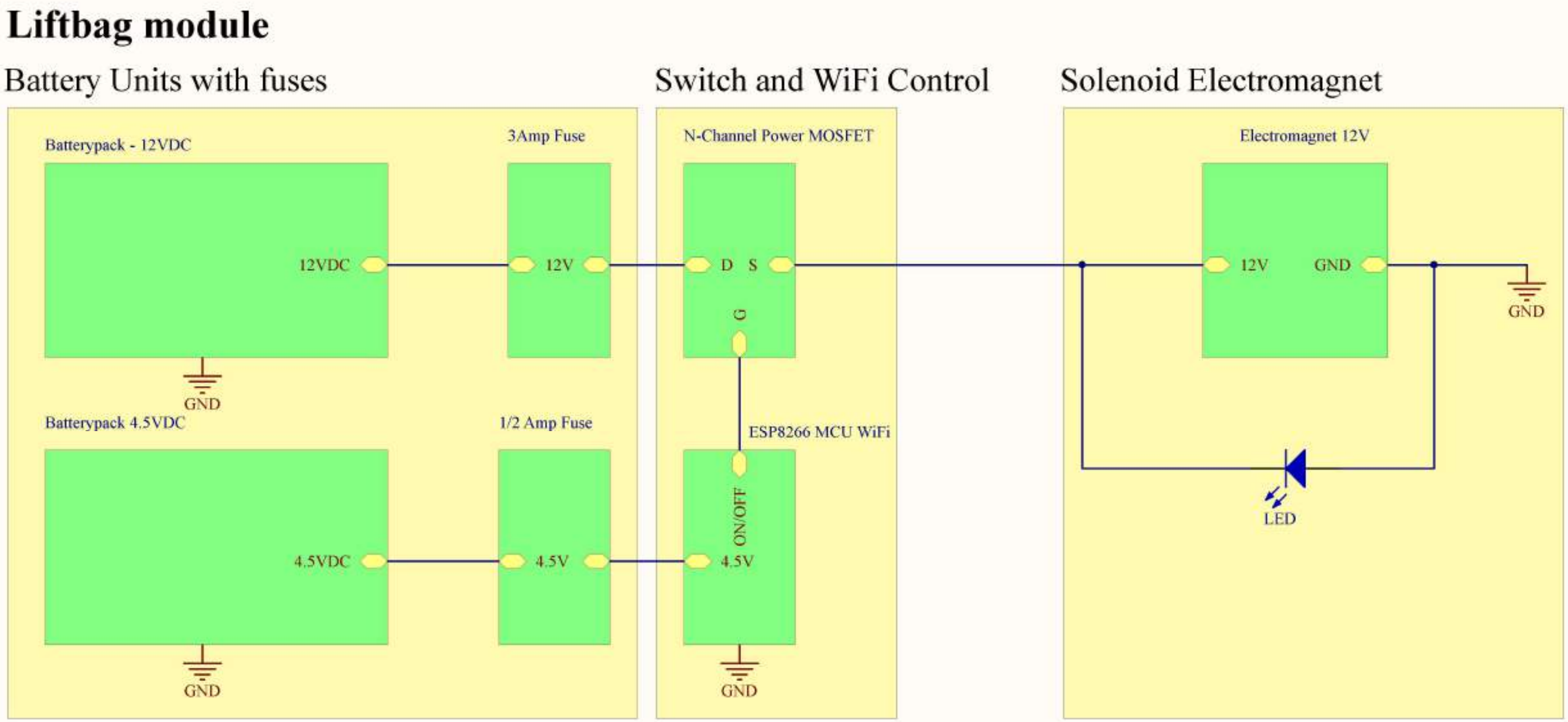
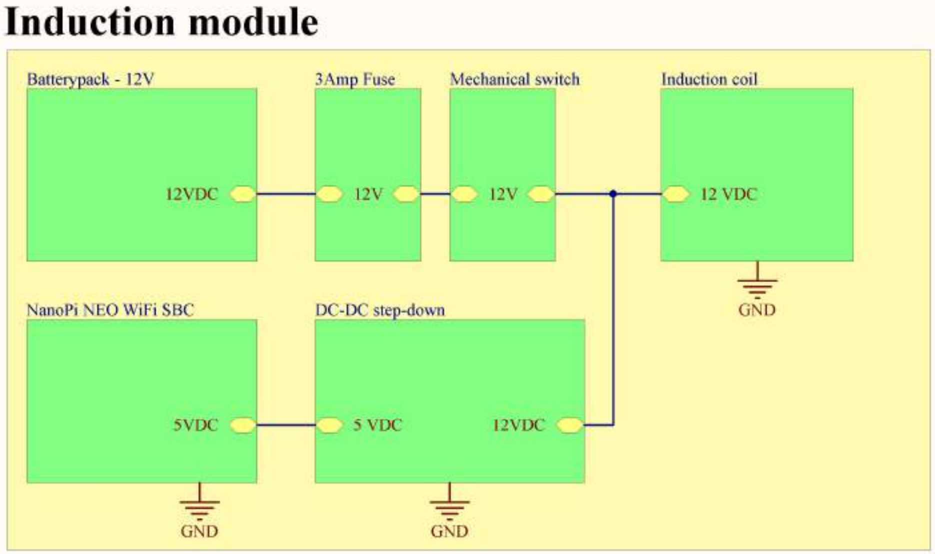


Figure 20: Mechanical drawings of the electrical housing and the bottom plate

B SID

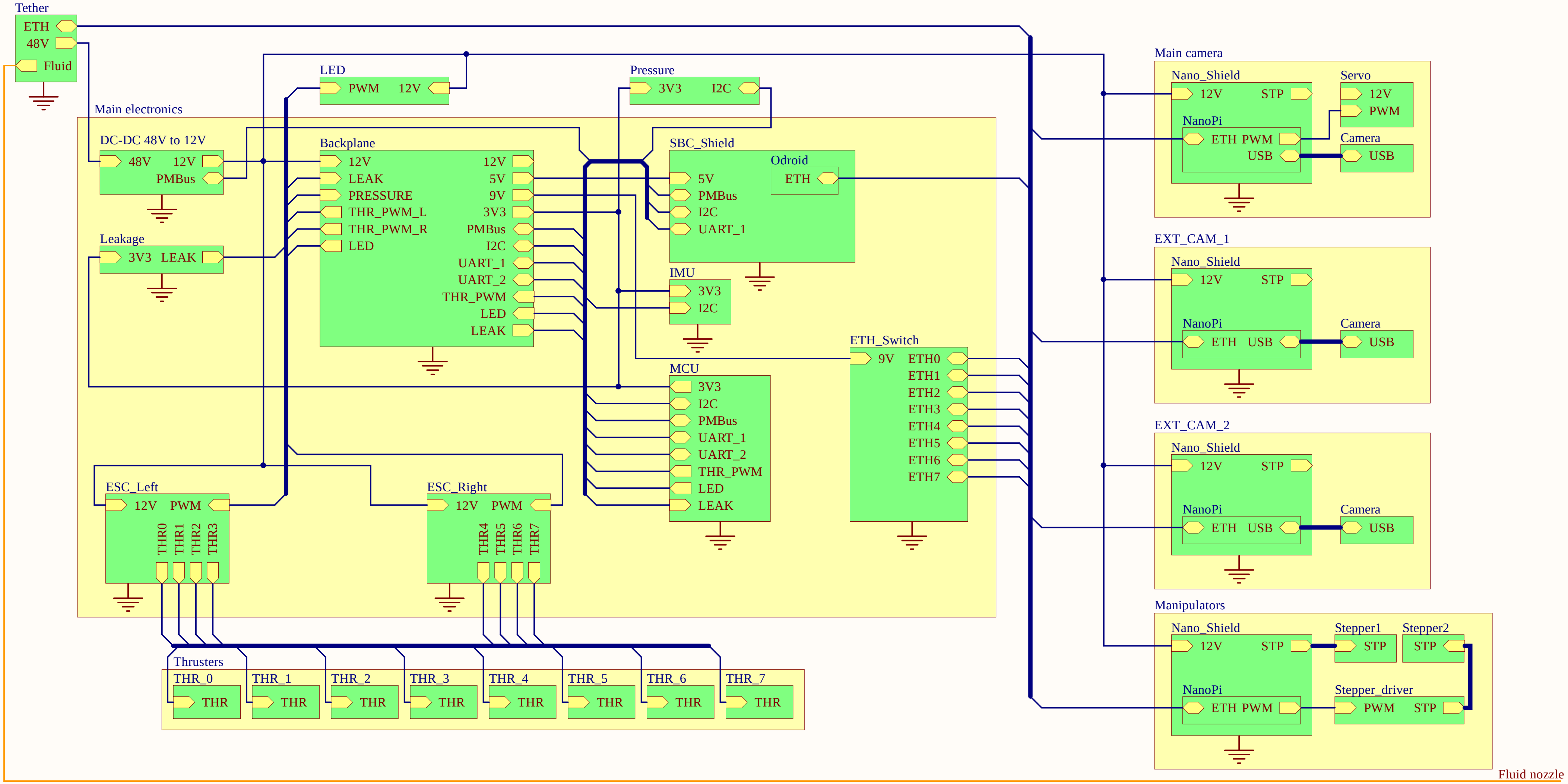




Title
Liftbag & Induction SID

Author
Sander Furre

Size			Rev
A4	VORTEX NTNU	Liftbag_SID.SchDot	*
[No Variations]	22.05.2018	Sheet no. 1 of 1	



Title

Subsea SID

Author

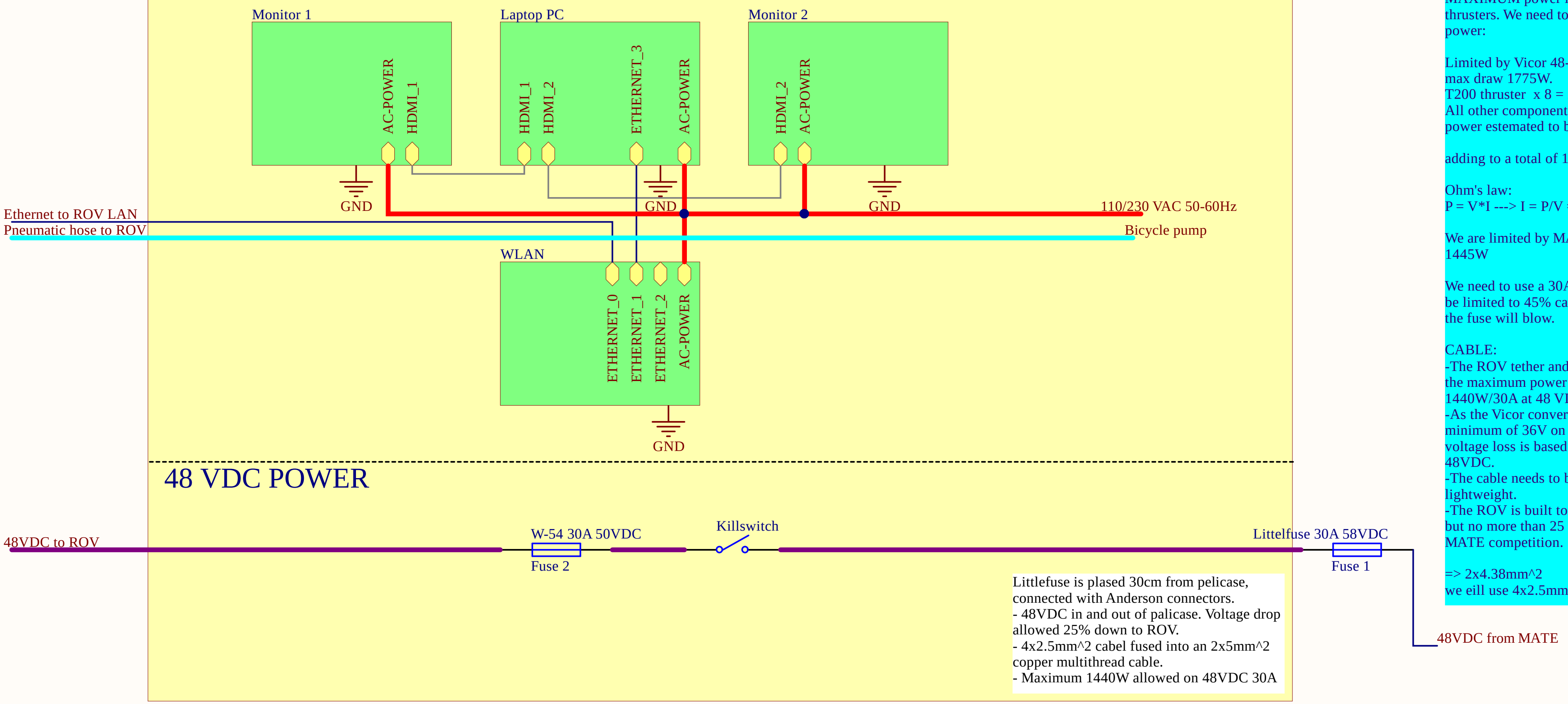
Kristoffer Hermansen

Size			Rev
A4	Vortex NTNU	Subsea SID.SchDoc	001

[No Variations] 20.05.2018 Sheet no. 1 of 1

Pelicase

110/230VAC 50-60Hz POWER & WLAN/LAN



Littlefuse is plased 30cm from pelicase, connected with Anderson connectors.
- 48VDC in and out of palicase. Voltage drop allowed 25% down to ROV.
- 4x2.5mm^2 cabel fused into an 2x5mm^2 copper multithread cable.
- Maximum 1440W allowed on 48VDC 30A

Fuse calculations:

48VDC:
MAXIMUM power in ROV is limited by the thrusters. We need to use software to limit this power:

Limited by Vicor 48-12DC converter with max draw 1775W.
T200 thruster x 8 = 2800W*0.45 = 1260W
All other components in ROV draw maximum power estemated to be 78W

adding to a total of 1338W

Ohm's law:
P = V*I ---> I = P/V = 1338W/48V = 27.8A

We are limited by MATE to use 30A at 48V = 1445W

We need to use a 30A fuse. Thrusters need to be limited to 45% capasity with software or the fuse will blow.

CABLE:
-The ROV tether and power cable is based on the maximum power consumption of 1440W/30A at 48 VDC.
-As the Vicor converter in the ROV allows a minimum of 36V on its primary side, the voltage loss is based on maximum 25% of 48VDC.
-The cable needs to be flexible and lightweight.
-The ROV is built to go as deep as 100 meter, but no more than 25 meter is needed for the MATE competition.

=> 2x4.38mm^2
we eill use 4x2.5mm^2 = 2x5mm^2

Title	Pelicase and power calculations
Author	Benjamin Askelund
Size	A4
Vortex NTNU	Pelicase.SchDoc
Rev	1.0
[No Variations]	20.05.2018
Sheet no. 1	of 1