VORTEX
NTNU

Technical Report

Norwegian University of Science and Technology
Trondheim, Norway

ROV: Maelstrom

May 2016

Maelstrom

Technical Report
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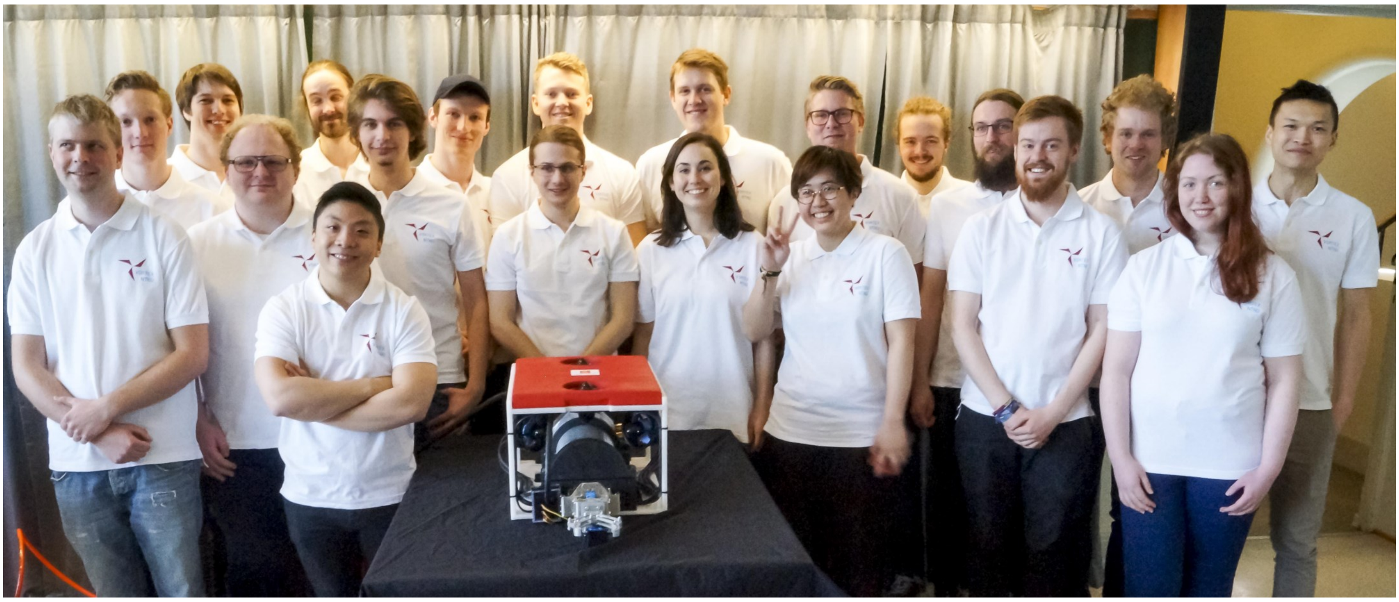


Team Members:

	Year of study:
Ole Johan J Lønnum *(CEO)*	3
Marie Henriksen *(CFO)*	2
Morten Liland *(CTO)*	5
Vedbjørn Kjerstad *(CMO)*	2
Kristian Bortne *(Mechanical)*	2
Arne Bui *(Mechanical)*	2
Greatania Juardi *(Mechanical)*	2
Sarah A. Prescott *(Mechanical)*	2
Karl Ylvisaker *(Electronics)*	2
Lars H. Andersen *(Electronics)*	4
Simon L'orange *(Electronics)*	4
Peter Aaser *(Control)*	4
Morten F. Amundsen *(Control)*	4
Eirik Lothe Foseid *(Control)*	2
Alexander G. Wasaznik *(Manipulator)*	4

Mentors:

Daniel Tran	Material Engineering
Johannes P. Lorentzen	HSE and Physics
Mads Jøsok	Mechanical Engineering

Faculty Advisor:

Stefano Bertelli	Senior Engineer, NTNU

COMPANY SPECIFICATIONS:

Company Name: Vortex NTNU

Webpage: www.vortexntnu.no

Country: Norway

City: Trondheim

Distance Traveled: 7 808,96 km

ROV Name: Maelstrom

Years Entered: 1

University: Norwegian University of Science and Technology (NTNU)

Sponsors:

Abstract

Significant challenges in space and sub-sea exploration are the potentially long travel distances and hostile environments. These obstacles can be solved with a general purpose ROV, equipped with specialized instruments and tools, suited for a wide range of tasks, including oil well capping, retrieving mission-critical equipment and samples, imaging as well as depth measurements.

In this document, you will find the technical specification and documentation for the entire Maelstrom ROV system, as well as a job safety analysis for the operation of the ROV system produced by Vortex NTNU.

Contents

1 Introduction

Vortex NTNU is an independent student organization at the Norwegian University of Science and Technology (NTNU) in Trondheim, Norway. For the first time, Vortex NTNU will participate in the MATE ROV competition. Our team is composed of 20 students from different engineering disciplines from all levels of bachelor and master degree programs. Our purpose is to provide an ideal opportunity for ambitious students to explore and develop their talents and skills in a collaborative undertaking. Through the project, we demonstrate that we can deliver a complex and integrated product in the demanding environment of an underwater competition.

1.1 Safety

Safety is a primary concern of Vortex NTNU. Our safety system is designed around the ALARP (*As low as reasonably possible*) principle [1], aiming to reduce risk to the lowest reasonable level. Design and manufacture are done according to the best safety practices stipulated by NTNU's HSE handbook and Norwegian HSE regulations. All new members of Vortex NTNU are given a safety briefing upon joining the team, followed by monthly safety briefings.

1.1.1 Risk Analysis

During design and planning, we have used risk analysis actively to identify possible hazards. We have used Job Safety Analysis when conducting new and potentially dangerous operations. A Primary Hazard Assessment [1] has been used to identify any possible hazards regarding ROV design.

1.1.2 Handling of Chemicals

The manufacturing process of the ROV requires chemicals as resin, solvents, and paints among others. We have used a chemical management system following Norwegian regulations, involving proper storage, risk analysis, and personal protective equipment. All chemical datasheets are available at the storage location.

1.1.3 Designed for Safety

We have prioritized safety during the design process. All features of the ROV are designed for high levels of safety. Safety is included as a design requirement for all parts and features in the specification phase. Safety features include the choice of wet connector type as described in section 2.2.4 and design of Man-Machine Interface.

1.1.4 Operational Safety

We have conducted a JSA in accordance with the regulations of the MATE ROV competition [2]. Based on the JSA, we have compiled an ROV operations procedure that is used for all ROV operation. The procedure is regularly updated based on experience gained.

2 Design Rationale

The design process was heavily influenced by the logistics and organizational structure of Vortex. As Vortex was founded less than one year ago, the organization has experienced constant growth and changes during the entire production cycle. In the beginning, we lacked a workshop area, facilities, equipment, and funding, resulting in us designing the ROV under a high degree of uncertainty. To combat this level of uncertainty, Vortex engineers designed several alternatives based on different expected manufacturing options and funding levels. These designs were also checked to make sure that most of the ROVs subsystems can be reused or exchanged with self-designed equivalents in future revisions of the ROV. These designs were merged into a concurrent design as the process evolved and we received further funding, facilities and manufacturing possibilities. The following section will explain the necessary details of how the ROV was designed, manufactured and tested.

2.1 Mechanical

This section will go through the mechanical details of the Maelstrom ROV.

2.1.1 Framework

The frame consists of four 10 mm thick plates connected by acid and corrosion resistant screws. The plates were made from polyoxymethylene (POM), also known as acetal. POM is an engineering thermoplastic and was selected as the material for the framework due to its high stiffness, low friction, and excellent dimensional stability. The frame was drafted in Autodesk Inventor and converted to `.stl` files. These files together with machine drawings were sent to Kongsberg Maritime where the frame was milled using a 5-DOF CNC mill. Emphasis was laid on constructing the smallest possible framework due to the requirements of the product demonstration. The main dimensions of the frame were given by the size of the electrical housing and providing enough water flow to the thrusters.

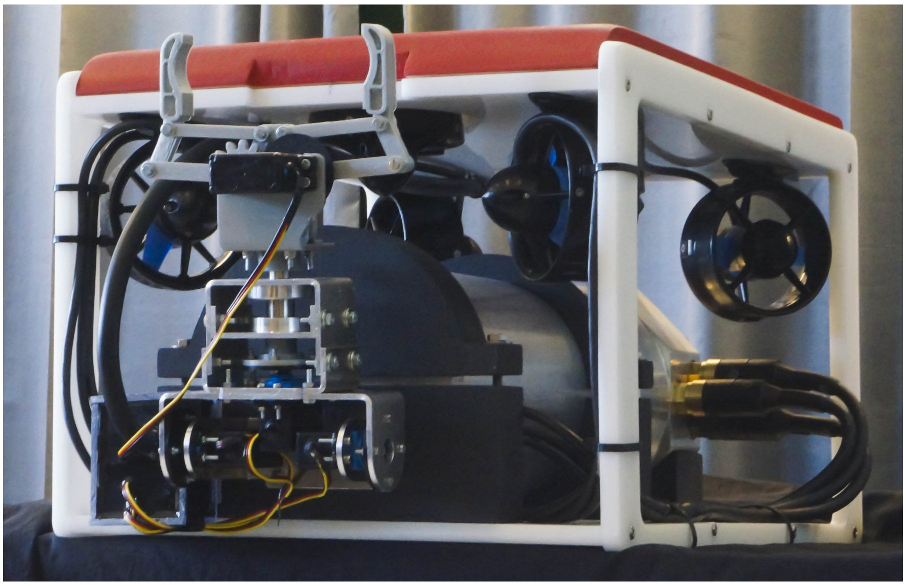


Figure 2.1: The Maelstrom frame

2.1.2 Electrical Housing

Maelstrom features a cylindrical housing with a hexagonal cap located in the middle of the framework with the possibility for quick removal or attachment. The quick removal allows for immediate access to the electronics by removing four bolts and disconnecting the connectors. The housing encloses all the electronics needed for power and control subsea.

Aluminium 6082-T6 was chosen as the material for the housing due to its high compressive yield strength relative to mass, corrosion resistance and high thermal conductivity. The cylindrical shape was selected to ensure that the heat generated by the electronics could be efficiently transferred to the water. The cylindrical shape is optimal to provide enough air space in the housing and surface area for efficient heat transfer. Further, the cylindrical shape gives a lower drag coefficient compared to for instance a rectangular cross-section.

The hexagonal cap is the connection point for the connectors and was designed to provide a flat surface to ensure a tight fit for the connector O-rings. Both the cap and the casing is threaded and fitted with an O-ring to provide a waterproof connection. Kongsberg Maritime also assisted with milling of the electrical housing.

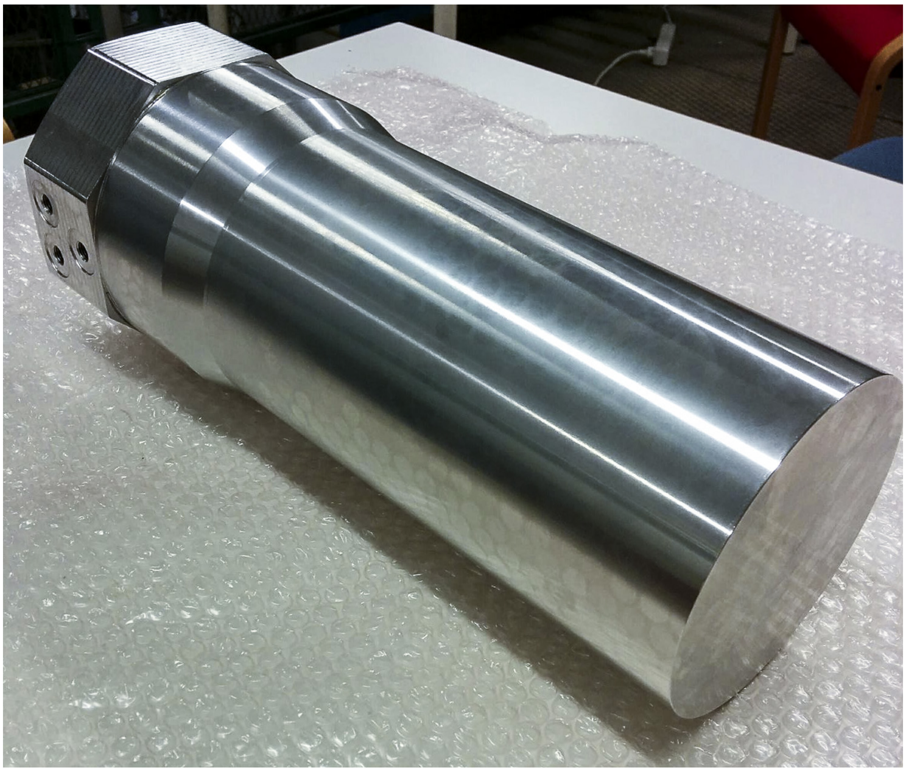


Figure 2.2: Assembled electronic housing.

2.1.3 Stability and Seakeeping Abilities

During the entire design process, a complete CAD model was created and updated to calculate: Distance from keel to the centre of gravity (KG) and centre of buoyancy (KB), displacement (∇) and the second moment of inertia (I) about G. These parameters were then used to find the geometric metacenter height (GM), which is a commonly used design parameter for stability in naval architecture.

The geometric metacenter height is given by:

$$GM = KB + BM - KG \tag{2.1}$$

where,

$$BM = \frac{I}{\nabla} \tag{2.2}$$

Vortex engineers could then iteratively find the placement of each component to ensure the optimal stability. Maelstrom has, therefore, a design GM, which gives a large righting moment that works in conjunction with the dynamic positioning system to create a stable platform for operations.

The necessary amount of buoyancy was determined from the CAD model and used with the stability calculations to determine the geometric shape of the buoyancy element. The buoyancy system was engineered to provide Maelstrom with a small amount of positive buoyancy so that the ROV would resurface in the event of a power failure. Divinycell H Grade 130, a sandwich structure, was used to build the buoyancy system.

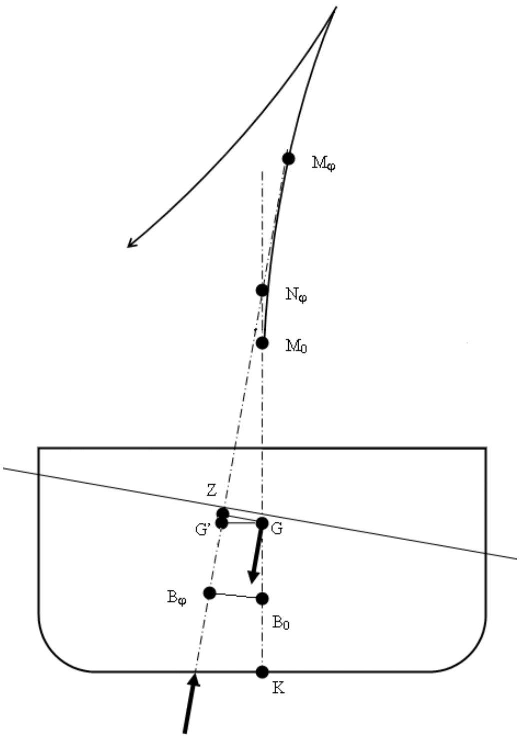


Figure 2.3: Sea vessel stability

2.2 Electrical

2.2.1 Hardware

When composing the system of Maelstrom, we have always had in mind future generations of the VortexNTNU project. We have gone for a modular based design, so that each part simply can be improved and replaced individually, without having to redesign the rest of the system. The appended SID-diagrams shows the complete system and how it is connected. The electrical hardware of Maelstrom is composed of:

- Tether
- Wet-Connectors
- Raspberry Pi 2 Model B
- Arduino Mega
- 48V to 12V power supply
- 48V to 5V power supply
- Motors
- Afro Esc 30A motor controller
- Manipulator
- IMU sensor
- Temperature sensor
- Camera

Below follows a brief explanation of each part and its use.

Tether

The tether is composed of a power transmission line with two pairs of 2.5 mm^2 copper wires, an ethernet cable for communication with topsite and two RG-174 coaxial cables for the video feed. These cables are bundled together to form the ROVs tether.

Wet-Connectors

The wet connectors are industrial grade, from AK Industries ”HydroVolt” series.We have a total of 60 pins available, which we use 48 of (redundancy due to thought for later iterations of the Vortex NTNU project). There is one connector for each motor, two for sensors, one for the manipulator and lastly one for the tether.

Raspberry Pi 2 Model B

The Raspberry Pi serves as the subsea brain and communications hub of the system. Our Dynamic positioning system runs from the Raspberry Pi, which then communicates the required changes in thrust to our AdaFruit PWM Driver. The Raspberry Pi is also handling all sensor data. The Raspberry Pi was chosen for its versatile, plug-and-play compatibility with most systems and the availability of open-source code to go along with it. Our ROV's system is based on the Robotic Operating System(ROS) - explained further in depth later in this document - which is implemented on the Raspberry Pi.

AdaFruit 16-Channel PWM/Servo Driver

The AdaFruit PWM Driver was chosen for its hardware PWM pins. The PWM Driver takes cues from the Raspberry Pi, and then outputs the required PWM-signal to motors and manipulator servoes. The addition of a dedicated PWM component was necessary due to the Raspberry Pis' lack of hardware PWM pins.

230V AC to 48V DC Power Supply

As there is no 48V DC commonly available, an RSP-1500-48 from Mean Well was used to convert from wall socket power to the 48V DC required by the MATE competition. This power supply features short circuit, overvoltage, overcurrent and temperature protection and can handle a total power of 1536 W

48V to 12V Power Supply

The power supply is an SD-1000L-12 from Mean Well and comes with the features short circuit, overvoltage, overcurrent and temperature protection. This power supply is capable of delivering up to 1000 W. It is used to takes the voltage down from 48V to 12V and powers both motors and sensors. As seen in the SID there is a fuse on the topside end of the tether leading to the power supply, which limits its current draw to 40 A maximum.

48V to 5V Power Supply

The power supply is an SD-15C-5 from Mean Well. This power supply is used to power the Raspberry Pi also protected from short circuits and overvoltage. As seen in the SID there is a fuse prior to the power supply; that limits its current draw to 3A maximum.

Thrusters

All six thrusters are of type T-100 from Blue Robotics.They run on 12V, with a current draw up to 12A each. We have implemented a software limit for the maximum speed of the motors to reduce the maximum current draw from the system.

Stemmer det med 50%? -¿ Gjør det på papiret i vertfall nå

Afro Esc 30A Speed Controllers

The speed controllers are of type Afro ESC 30A with a custom firmware from Blue Robotics. They receive a PWM signal, along with 12VDC power to supply each motor.

Manipulator

Consists of four waterproof servos, receiving power and signal from a single WET-connector. The servos are powered trough an independent power supply, reducing the voltage from 12 to 6V.

IMU Sensor

Onboard is an IMU and depth sensor from OpenROV. The IMU is a BNO055 sensor from Bosch and is also equipped with an MS5837-30BA depth sensor from Measurement Specialties. The IMU provides the main input to the regulator, including pressure, accelerometer, and gyroscope.

Temperature Sensor

The temperature sensor, a DS18B20 from `www.sparkfun.com`. The DS18B20 has a maximum range of -55° to $+125^\circ$ and is mounted on the manipulator for providing pinpoint-readings.

Camera

The camera is of type RS-Component Pro. The analog output from the camera is brought to topside trough a separate coaxial cable. The camera itself is encased in a resin cast, to increase waterproofing.

2.2.2 Waterproofing

All wire connections exposed to water have been waterproofed using 3M ScotchCast Insulating Resin combined with PVC-pipes for stress-relief.

2.2.3 System Draw Calculations

The system current draw and fuse calculations are found on the Topsite SID, appended to the back of this document.

2.2.4 Safety Design Choices

Safety has always been a major concern in the developing and building process. Our primary concern while working on the electrical hardware was limiting the possibility of receiving an electrical shock. We've countered this by covering all accessible wiring, and making sure no pins with a standing voltage is accessible. As an example the choice of wet connectors, where we have chosen to use Female bulkheads on the outside of the cylinder - as to not have any accessible pins - except for the tether's, which is Male pins. The Male pins make it impossible for anyone to touch a pin unintentionally with a standing voltage and is an excellent example of how we have worked and thought regarding the rest of the system. We've also utilized routines for checking the system after we've made changes to it before we're allowed to power it up.

2.3 Control System

The control software for Maelstrom is implemented in the form of loosely coupled nodes residing both topside and on a Raspberry Pi in the ROV. These nodes are implemented using the open source Robot Operating System (ROS) which makes communication between nodes seamless and easy, even between topside and subsurface. The overall structure and communications of the control system are shown in Figure 2.4. All nodes, including the control algorithm (Section 2.3.3) are implemented from scratch.

2.3.1 ROS

ROS is an open source framework for developing software for robotics, originating from Stanford. The gist of ROS is that it takes care of all the tedious and error prone plumbing necessary for communication between processes, especially for processes residing on different hardware. The programmer is left with very powerful abstractions such as ROS *nodes*, *topics* and *services*. For instance, in Figure 2.4, the "Controller input" node advertises a topic with the name "Joystick input", and periodically broadcasts messages on this channel. The "Human machine interface" node residing on the Raspberry Pi is not aware of the Controller input node, but only of the Joystick input topic to which is subscribed. This design method allows for a very modular, robust and decoupled system.

2.3.2 Components

The main components of the software control system shown in Figure 2.4 are detailed in the following.

Controller Input

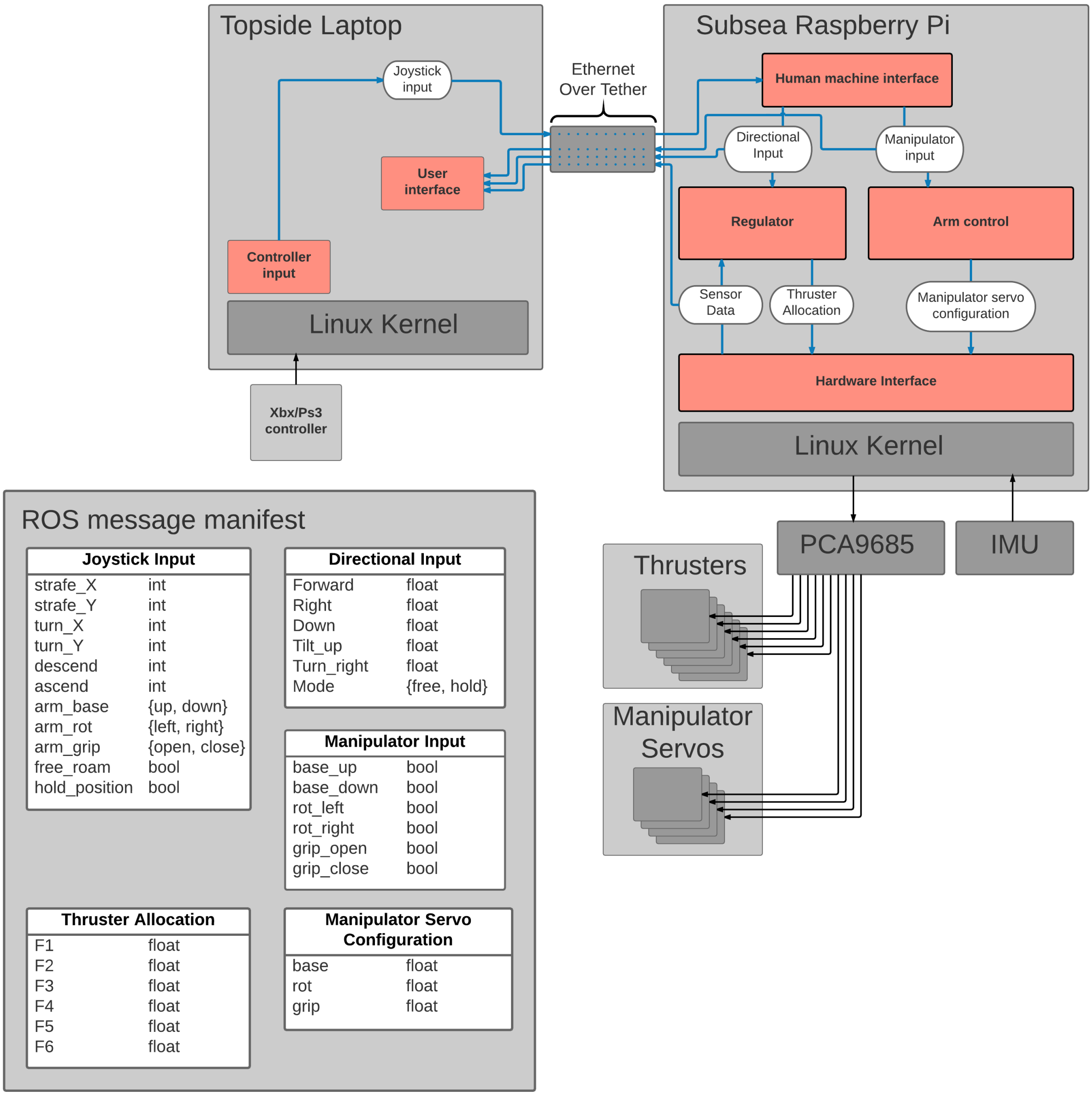
The controller input module is responsible for reading signals from an Xbox 360 controller, and broadcasting human readable messages.

Human Machine Interface

This node subscribes to the joystick input topic to read the messages from the controller input node. When a joystick input message arrives the Human machine interface extracts the directional input component and creates a directional input message which is broadcast on the directional input topic and the other way around for arm input messages.

Arm Control

The arm control module keeps track of the current state of the manipulator and broadcasts the desired servo configuration to the hardware interface node.



Joystick Input	
strafe_X	int
strafe_Y	int
turn_X	int
turn_Y	int
descend	int
ascend	int
arm_base	{up, down}
arm_rot	{left, right}
arm_grip	{open, close}
free_roam	bool
hold_position	bool

Directional Input	
Forward	float
Right	float
Down	float
Tilt_up	float
Turn_right	float
Mode	{free, hold}

Manipulator Input	
base_up	bool
base_down	bool
rot_left	bool
rot_right	bool
grip_open	bool
grip_close	bool

Thruster Allocation	
F1	float
F2	float
F3	float
F4	float
F5	float
F6	float

Manipulator Servo Configuration	
base	float
rot	float
grip	float

Figure 2.4: An overview of Maelstrom's modules and their communication. Blue arrows indicate ROS topics, black arrows indicate other communication. All ROS processes can subscribe to any topic, the lines simply denote which nodes actively publish and listen to topics.

Regulator

The regulator takes care of the motion control of the ROV. Due to its complexity and importance, it is explained in further detail in Sections 2.3.3–2.3.5.

Hardware Interface

In order to drive the thrusters and servo motors, a PCA 9686 board is attached to the Raspberry Pi. The hardware interface reads the thruster allocation and servo configurations desired by the regulator and arm control modules and translates these to PWM duty cycles which are then sent to the PCA 9695 over I^2C. Additionally, the Hardware interface collects sensor data from the IMU and broadcasts these to the regulator.

2.3.3 Feedback Controller

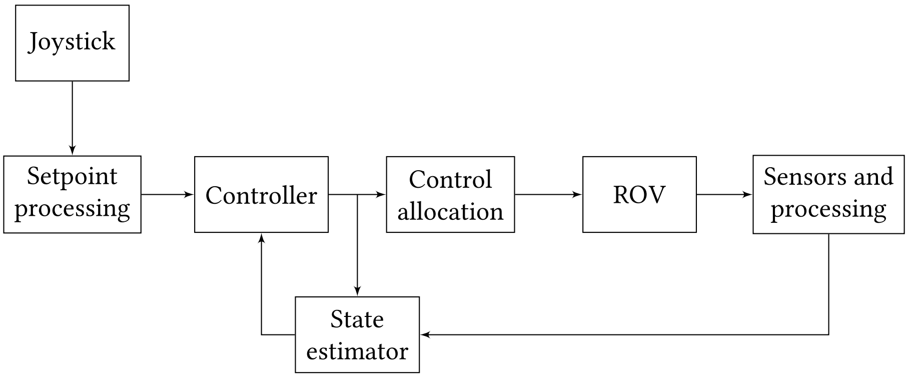


Figure 2.5: Maelstrom's feedback control system

To make it easy to fly the ROV, we have implemented a feedback control algorithm formulated in six degrees of freedom (DOF). This is the number of DOFs in which the ROV can move, i.e. position in three spatial dimensions and orientation around three axes. The placement of the six thrusters allows us to control all DOFs except for roll (rotation about the forward axis). When we fly the ROV, the pilot can switch between feedback and open loop control modes. The open loop control mode lets the pilot set the surge/sway/heave forces and pitch/yaw moments directly. By combining the feedback controller and the open loop controller, we can choose which DOFs to control automatically, and which to control manually. An example is automatic control of orientation and depth, combined with manual control of forward and sideways motion. The specific algorithm used is a nonlinear, quaternion-based, PD[1] controller, accepting position and orientation (collectively termed *pose*) as setpoints. It is described in detail in [3], and the control law is

$$\boldsymbol{\tau} = -\boldsymbol{K}_D\boldsymbol{\nu} - \boldsymbol{K}_P(\boldsymbol{q})\boldsymbol{z} + \boldsymbol{g}(\boldsymbol{q}) \tag{2.3}$$

where

- $\boldsymbol{\tau} \in \mathbb{R}^6$ are control inputs for all 6 DOFs,
- $\boldsymbol{q} \in \mathbb{R}^4$ is a quaternion vector describing orientation error,
- $\boldsymbol{\nu} \in \mathbb{R}^6$ is a vector of angular velocities,
- $\boldsymbol{z} \in \mathbb{R}^6$ is a vector representing error in pose,
- $\boldsymbol{K}_D \in \mathbb{R}^{6\times6}$ is a positive definite matrix of derivative gains,
- $\boldsymbol{K}_P(\boldsymbol{q}) \in \mathbb{R}^{6\times6}$ is a nonlinear matrix of proportional gains, and
- $\boldsymbol{g}(\boldsymbol{q}) \in \mathbb{R}^6$ is a vector of restoring forces (resulting from gravity and buoyancy).

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[1] A PD controller is a controller with proportional and derivative gain, a variant of the well-known PID controller.

2.3.4 Control Allocation

The control inputs $\boldsymbol{\tau}$ calculated by the algorithm in the previous section are given separately for each DOF. That is, $\boldsymbol{\tau}$ are forces and moments that must be acted out by the ROV. These forces and moments must be converted to inputs for each thruster. We do this by solving a least squares optimization problem, as detailed in [4] and Chapter 12.3.2 of [5]. This minimizes the total thruster force commanded while ensuring that the commanded $\boldsymbol{\tau}$ is fulfilled. This is formulated as

$$\boldsymbol{u} = \boldsymbol{K}^{-1}\boldsymbol{T}^{\dagger}\boldsymbol{\tau} \tag{2.4}$$

where $\boldsymbol{K} \in \mathbb{R}^{6\times6}$ is a thrust coefficient matrix, and $\boldsymbol{T}^{\dagger} \in \mathbb{R}^{6\times6}$ is the generalised inverse of the thrust configuration matrix $\boldsymbol{T}$. $\boldsymbol{K}$ is in our case identity, while $\boldsymbol{T}$ describes the locations and orientations of the thrusters. $\boldsymbol{u} \in \mathbb{R}^{6}$ is the vector of forces in Newton required from each thruster.

2.3.5 State Estimator

The feedback controller depends on estimates of the ROV states. Some of the required values are calculated on board the IMU, and those not directly available are estimated with a simple integration filter. The combination of these give us all the necessary inputs to the control algorithm.

2.4 Manipulator

To solve the tasks in the competition this year, we made a general purpose manipulator for the ROV with three degrees of freedom. The overall design of the manipulator is divided into three main parts, the gripper, the rotator and the elbow. We designed it to be modular, and in the case of failure, the elbow and rotator can be removed. In Figure 2.6 a 3D rendering of the manipulator show the three parts. We designed the tree elements with strength, durability and safety as the focus. Two ball bearings are used to ensure the structural forces needed in the rotation part.

2.4.1 Gripper

The gripper is designed to be able to solve all the tasks in the competition, from lifting small objects and picking up cables to manipulation larger objects. It makes use of the parallel principle to transform the rotational momentum of the servo to the gripping movement. This allows for high strength and a wide range of action. The configuration of the tip is still in the process of optimization by use of 3D printing and rapid prototyping.

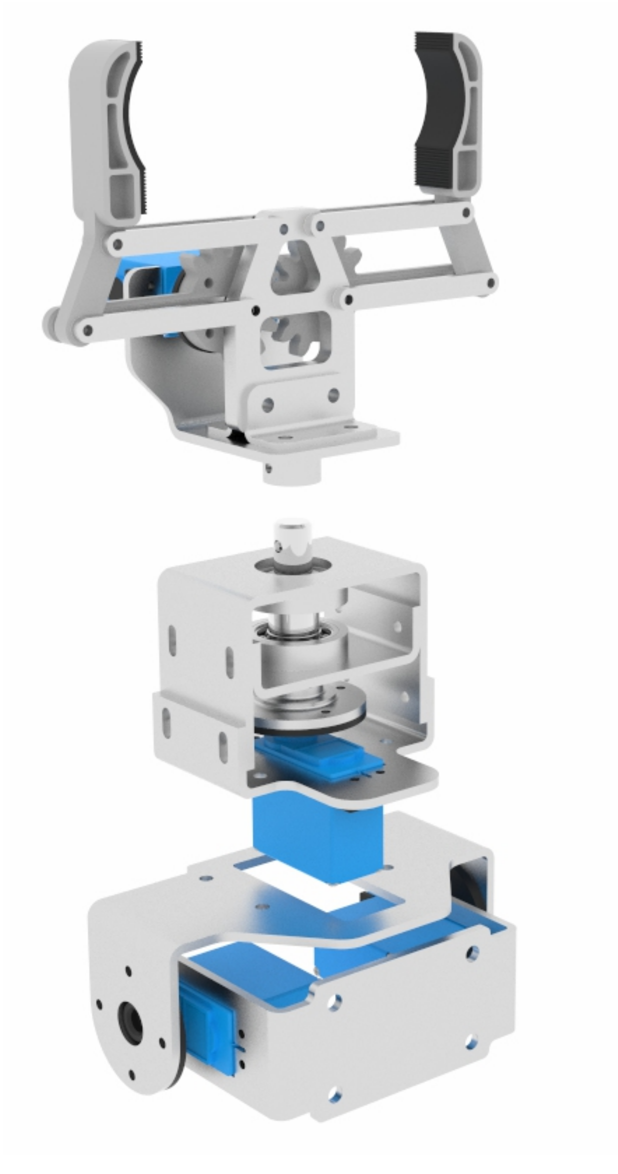


Figure 2.6: Exploded view of the Maelstrom manipulator arm

2.4.2 Actuators

We decided to use Hitec HS-646WP as the actuators on the manipulator as they are strong, durable and IP67 rated. We chose to use electrical actuators due to the higher complexity and safety requirements associated with the alternatives, hydraulics, and pneumatics. As the Hitec HS-646WP are IP67 rated, they are waterproof from the factory; only pressure compensation is needed to use them on the ROV. The pressure compensation was done by filling them with rapeseed oil.

In the elbow joint, two servos are working in tandem to enable the manipulator to lift heavier objects, such as the cube satellites. As the servos are counter rotating, they have to be synchronized this is done partly by aligning them properly when they are mounted and partly in software by introducing a tuning parameter.

3 Logistics

3.1 Project Management

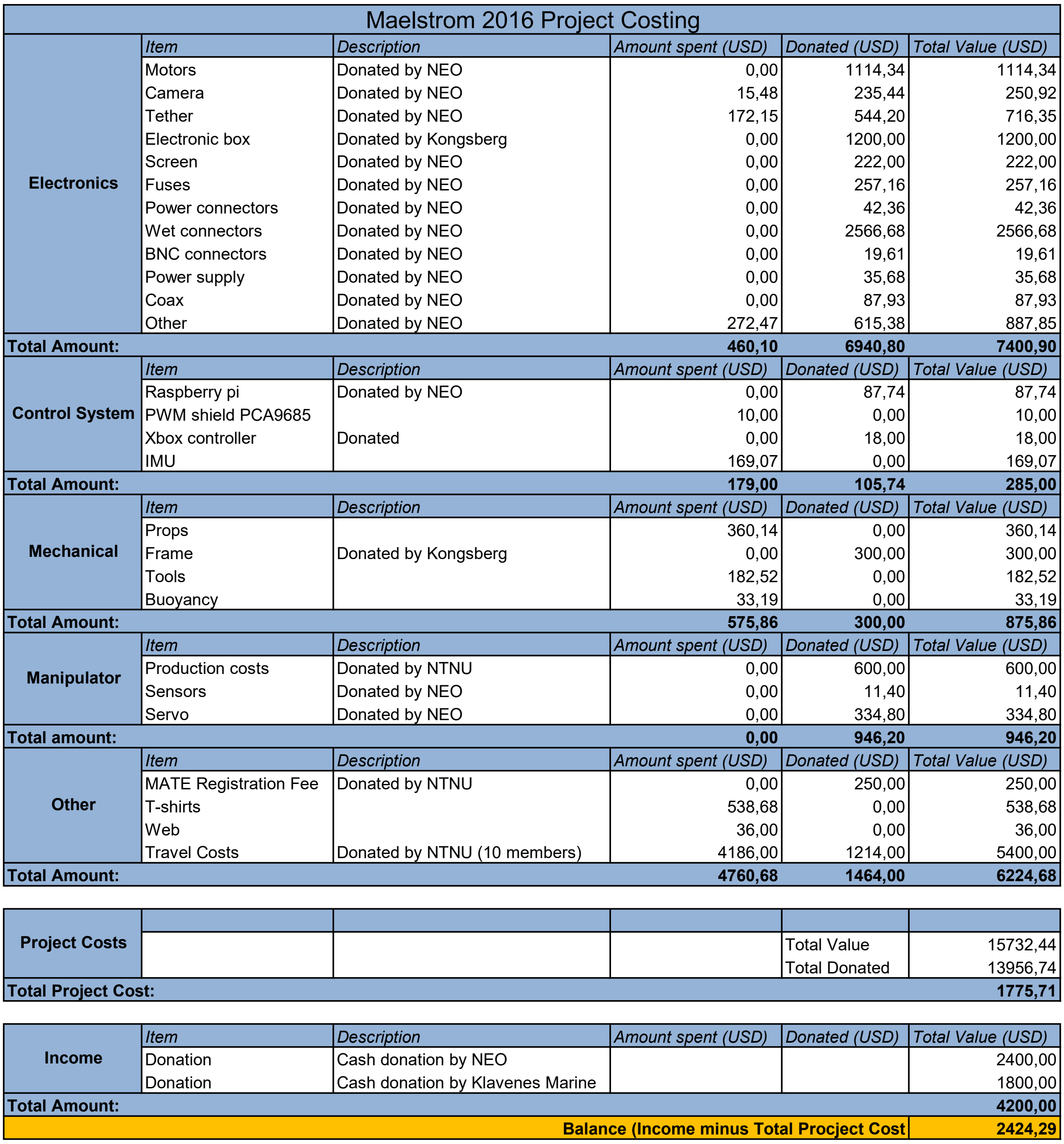
There is a small time span for the team to complete a full product development process to produce a capable ROV to compete in the MATE ROV competition. At project start, the management group drafts out overall plans, focus areas, needed competence, organizational structure, and budgets, in addition to recruiting highly motivated students. The design process starts with problem identification and concept development of all systems, before proceeding to design. Production and assembly start when all designs are finished. Currently, the organization is divided into six groups: the management, marketing, mechanical, electronics, control system, and manipulator group. The company CEO delegates responsibility to the group leaders of each department, who in turn has responsibility for all department engineers in the development of components and deliverables. The group leaders of each department set the goals to be achieved and make sure that components are delivered to schedule. Each week, the daily production targets and accomplishments are reviewed, and the schedule is updated to reflect the current progress. Production goals not met would be worked on individually by engineers between workdays. If the engineers continually did not meet the production goals, the CEO would have a short meeting to discuss whether more resources such as engineers should be assigned to finish the required production goals in time. In this way team spirit is enforced, and no one feels left alone or overloaded with work.

3.2 Source Code Management

The source code was managed using git, an open source version control system. Each sub-module of the control system as described in the software section was maintained in its own repository rather than having a single large repository. While the git standard allows for sub-modules within a single repository, we opted for the simpler split repository model because the team did not have enough git experience to use the more complex ”correct” method.

3.3 Budget and Project Cost

As this is Vortex’ first year, we have had no old stock to reuse. We received some of the necessary materials through donations and bought everything else. We chose some of our purchases specifically so that they may be reused later. This increased the number of necessary purchases and led to higher total expenses than what we expect from established teams. Also, the prices of domestic goods are in general higher than the prices of items purchased on-line from other countries. However, international shipping can be slow and expensive in itself, and this is why we have opted to buy most of our components within Norway, despite the higher cost. The 2016 Project Costing sheet is shown in Figure 3.3.



Maelstrom 2016 Project Costing

	Item	*Description*	*Amount spent (USD)*	*Donated (USD)*	*Total Value (USD)*
Electronics	Motors	Donated by NEO	0,00	1114,34	1114,34
	Camera	Donated by NEO	15,48	235,44	250,92
	Tether	Donated by NEO	172,15	544,20	716,35
	Electronic box	Donated by Kongsberg	0,00	1200,00	1200,00
	Screen	Donated by NEO	0,00	222,00	222,00
	Fuses	Donated by NEO	0,00	257,16	257,16
	Power connectors	Donated by NEO	0,00	42,36	42,36
	Wet connectors	Donated by NEO	0,00	2566,68	2566,68
	BNC connectors	Donated by NEO	0,00	19,61	19,61
	Power supply	Donated by NEO	0,00	35,68	35,68
	Coax	Donated by NEO	0,00	87,93	87,93
	Other	Donated by NEO	272,47	615,38	887,85
Total Amount:			**460,10**	**6940,80**	**7400,90**
	Item	*Description*	*Amount spent (USD)*	*Donated (USD)*	*Total Value (USD)*
Control System	Raspberry pi	Donated by NEO	0,00	87,74	87,74
	PWM shield PCA9685		10,00	0,00	10,00
	Xbox controller	Donated	0,00	18,00	18,00
	IMU		169,07	0,00	169,07
Total Amount:			**179,00**	**105,74**	**285,00**
	Item	*Description*	*Amount spent (USD)*	*Donated (USD)*	*Total Value (USD)*
Mechanical	Props		360,14	0,00	360,14
	Frame	Donated by Kongsberg	0,00	300,00	300,00
	Tools		182,52	0,00	182,52
	Buoyancy		33,19	0,00	33,19
Total Amount:			**575,86**	**300,00**	**875,86**
	Item	*Description*	*Amount spent (USD)*	*Donated (USD)*	*Total Value (USD)*
Manipulator	Production costs	Donated by NTNU	0,00	600,00	600,00
	Sensors	Donated by NEO	0,00	11,40	11,40
	Servo	Donated by NEO	0,00	334,80	334,80
Total amount:			**0,00**	**946,20**	**946,20**
	Item	*Description*	*Amount spent (USD)*	*Donated (USD)*	*Total Value (USD)*
Other	MATE Registration Fee	Donated by NTNU	0,00	250,00	250,00
	T-shirts		538,68	0,00	538,68
	Web		36,00	0,00	36,00
	Travel Costs	Donated by NTNU (10 members)	4186,00	1214,00	5400,00
Total Amount:			**4760,68**	**1464,00**	**6224,68**
Project Costs				Total Value	15732,44
				Total Donated	13956,74
Total Project Cost:					**1775,71**
	Item	*Description*	*Amount spent (USD)*	*Donated (USD)*	*Total Value (USD)*
Income	Donation	Cash donation by NEO			2400,00
	Donation	Cash donation by Klavenes Marine			1800,00
Total Amount:					**4200,00**
				Balance (Income minus Total Procject Cost	**2424,29**

Figure 3.1: Maelstrom 2016 Project Costing Sheet.

4 Conclusion

There are still potential for improvement in the ROV system. Some of the challenges, lessons learnt, and Future improvements are gathered in the following sections.

4.1 Challenges

Since Vortex NTNU was established in 2015 the organisation has expanded substantially over the last year, from 5 persons to more than 20 people in 2016. The tether has been a problem because of the stiffens in the cable, this has been solved but gave some delay and eat of the testing and pilot training time.

4.2 Lessons Learnt and Skills Gained

From the construction of the Maelstrom, we have learnt some important lessons. First of all is that the construction of a complex system takes time and that you might stumble upon problems that you could not anticipate. Examples of this are the shipping time and stock availability.
Another lesson that we learnt this year is that team management is a difficult task especially when the team is new, and the members lack experience in the field where they are going to work.

4.3 Future Improvements

The Maelstrom is our first ROV and has a lot of potential for future improvement. The primary challenge for the ROV has been the tether cable which initially was too stiff, which was solved by exchanging a commercially bought tether cable with a self-assembled tether that still need some minor improvement. The gripper is the first part that is under improvement, and will be further improved till a couple of days before departure. Other areas of improvement are to continue the work on the DP system by increasing to 6 DOF, optimising the design of the frame and reducing the size of the power converter. Most of the electronic hardware will be improved and designed to fit our system better than the commercially bought components that we use today.

Bibliography

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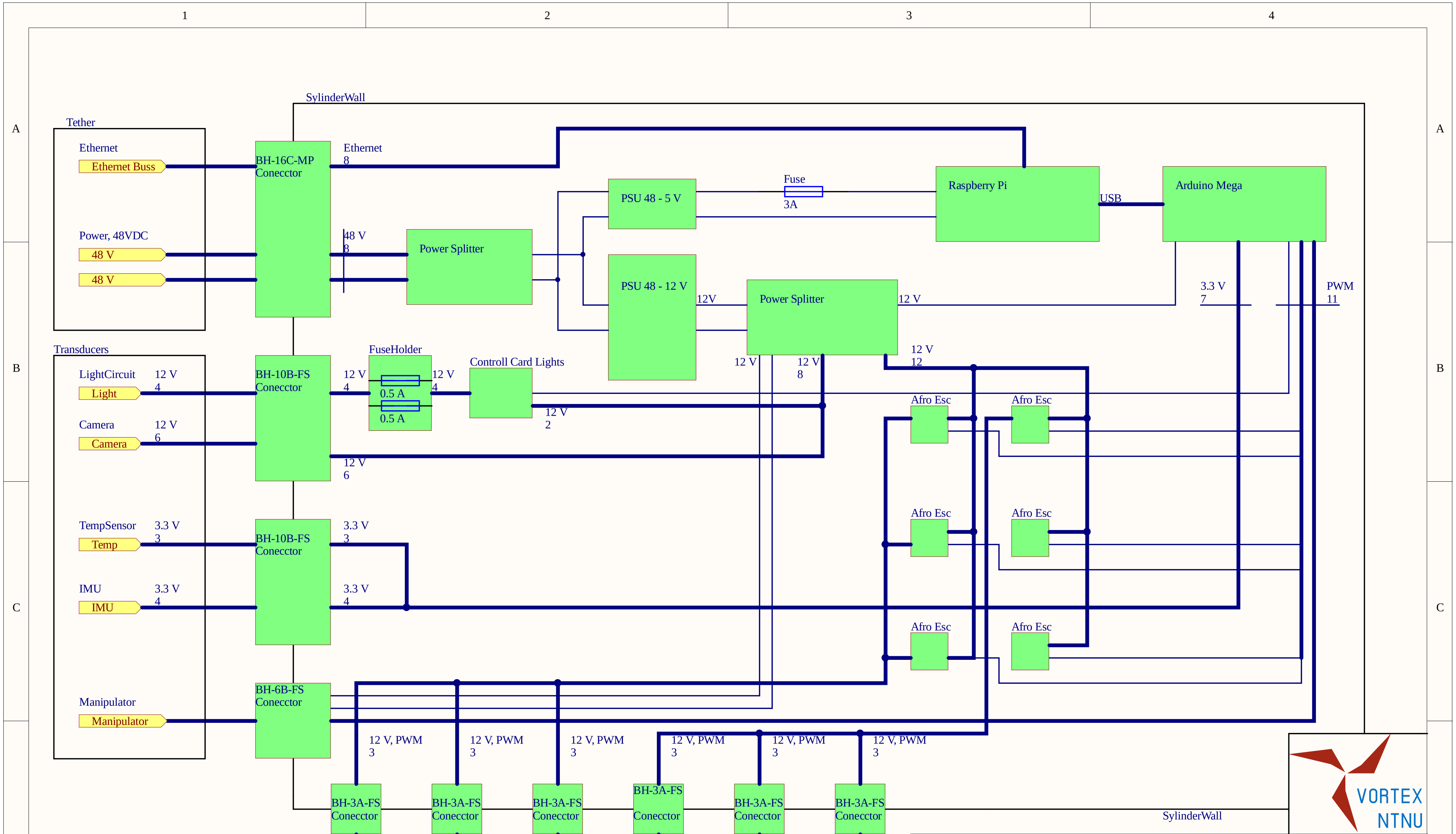
Appendices



Title: Subsea SID

Date: 2016-04-30

Revision: V 1.0

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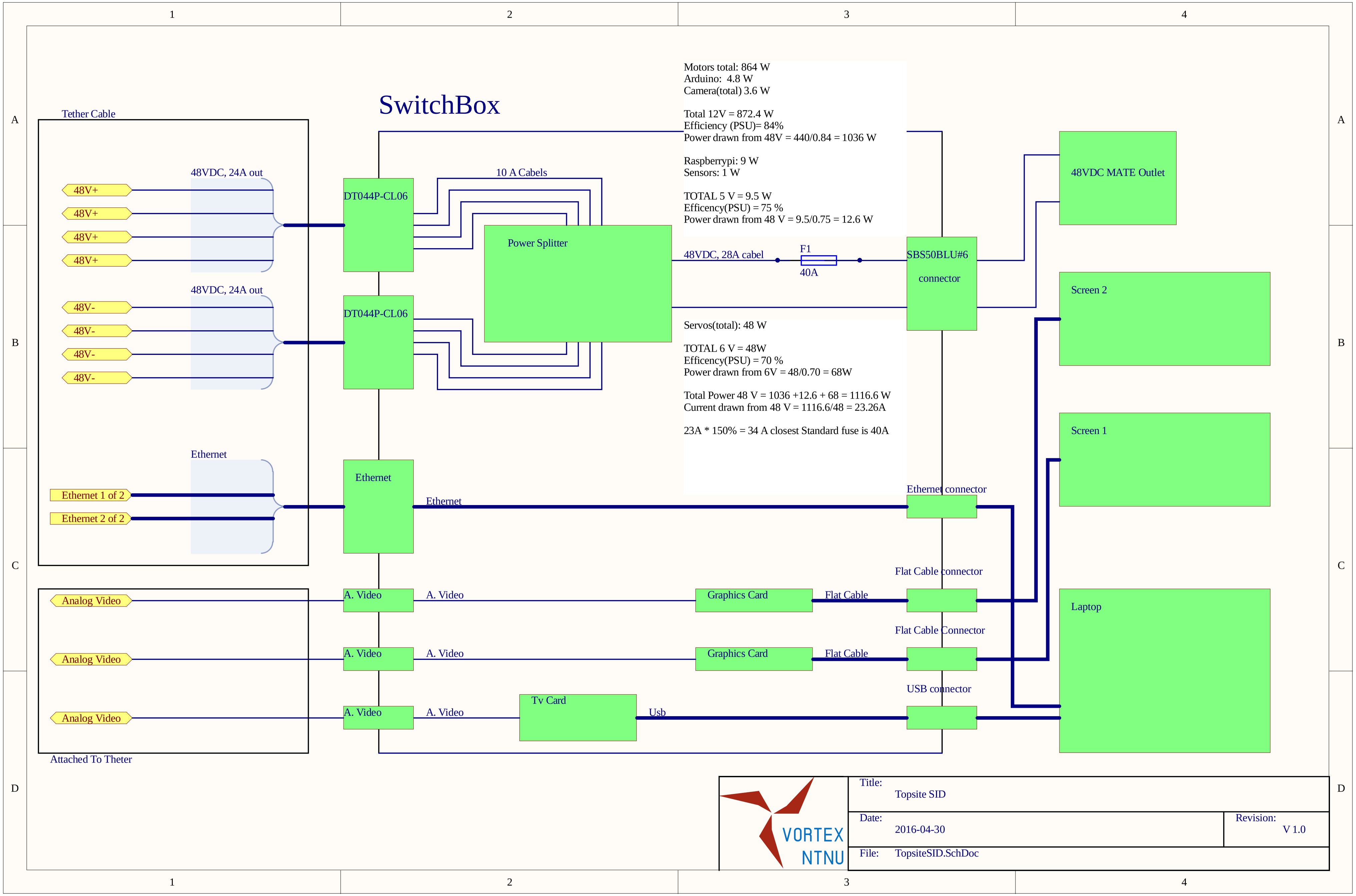
SwitchBox



Motors total: 864 W
Arduino: 4.8 W
Camera(total) 3.6 W

Total 12V = 872.4 W
Efficiency (PSU)= 84%
Power drawn from 48V = 440/0.84 = 1036 W

Raspberrypi: 9 W
Sensors: 1 W

TOTAL 5 V = 9.5 W
Efficency(PSU) = 75 %
Power drawn from 48 V = 9.5/0.75 = 12.6 W

Servos(total): 48 W

TOTAL 6 V = 48W
Efficency(PSU) = 70 %
Power drawn from 6V = 48/0.70 = 68W

Total Power 48 V = 1036 +12.6 + 68 = 1116.6 W
Current drawn from 48 V = 1116.6/48 = 23.26A

23A * 150% = 34 A closest Standard fuse is 40A

Title: Topsite SID
Date: 2016-04-30
Revision: V 1.0
File: TopsiteSID.SchDoc