Technical report 2015

UiS Subsea, University of Stavanger
Stavanger, Norway

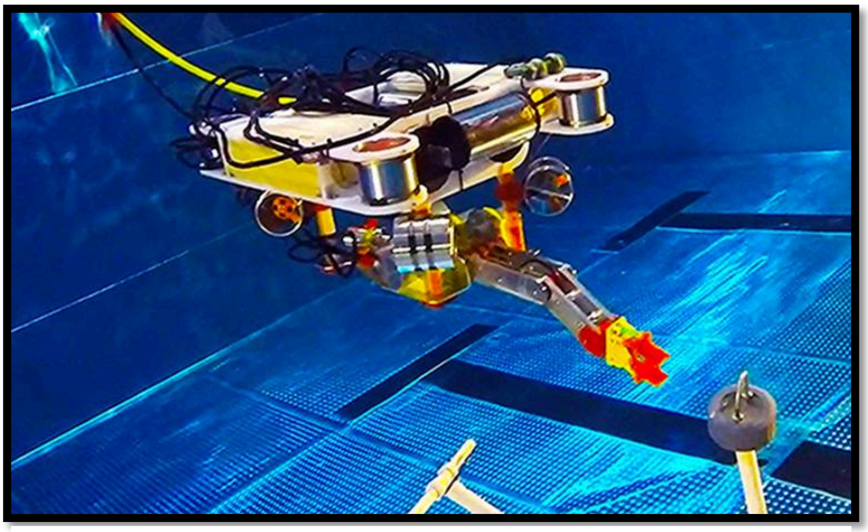


Figure 1: Thor, the 2015 UiS Subsea ROV

Prepared for:
MATE ROV Competition 2015, St. John's, Newfoundland, Canada.

Team members and roles:

Thorbjørn Johnsen	CEO and electrical engineer (thruster control)
Elisabeth V. Borg Baardseth	COO and software engineer (GUI and comm. systems)
Daniel Eidsvåg	CTO and electrical engineer (thruster control)
Martin Birkeland	CFO and mechanical engineer (manipulator control)
Mathias F. Bruset	Safety and mechanical engineer (thruster design)
William Evje Nodland	Electrical engineer (power distribution)
Torbjørn Reilstad	Electrical engineer (manipulator control)
Cato Sjonsti	Mechanical engineer (manipulator design)
Paul Nicolai Amundrud	Mechanical engineer (construction design)
Benjamin Øygarden	Mechanical engineer (manipulator design)
Leiv Børge Mjølhus	Mechanical engineer (thruster design)
Hans Opstvedt	Electrical engineer (camera and sensors)
Anders Apeland	Electrical engineer (camera and sensors)

Mentors:
Prof. Hirpa G. Lemu
Prof. Morten Tengesdal
Prof. Arnfinn Nergård

1 Abstract

UiS Subsea is a student organization located at the University of Stavanger, Norway, established in the academic year of 2013/2014. UiS Subsea participated as the first Norwegian team in the MATE ROV Competition in 2014. Our vision is to promote interest around subsea engineering and enhance cooperative skills across different technical disciplines. Counting approximately 50 engineering students we want to design and build at least one new vehicle every spring semester. The organization is currently divided into three divisions: a ROV team, an AUV team and a R&D research group.

This year's ROV, *Thor,* is designed to operate in arctic environments under heavy conditions. Thor is equipped with a 5-axis manipulator and a stabilization system to ease maintenance work and observation tasks under water, and all necessary sensors to meet the challenges given in the competitions demonstration part. It has eight powerful thrusters and can freely move in all directions in light sea currents. The software is designed to maintain flexibility, and a lot of user-defined settings have been implemented.

As for the previous year, the 2015 ROV have been named after a Norse god. *Thor* was counted as the second most powerful god. He was the king of war and ruled the weather with his hammer *Mjølnir*. We find Thor's qualities suitable for this year's ROV, which represents its strengths and features. [1]

The 2015 ROV team counts 20 bachelor students within electrical-, machine- and computer engineering, who all have based their bachelor thesis on this project.

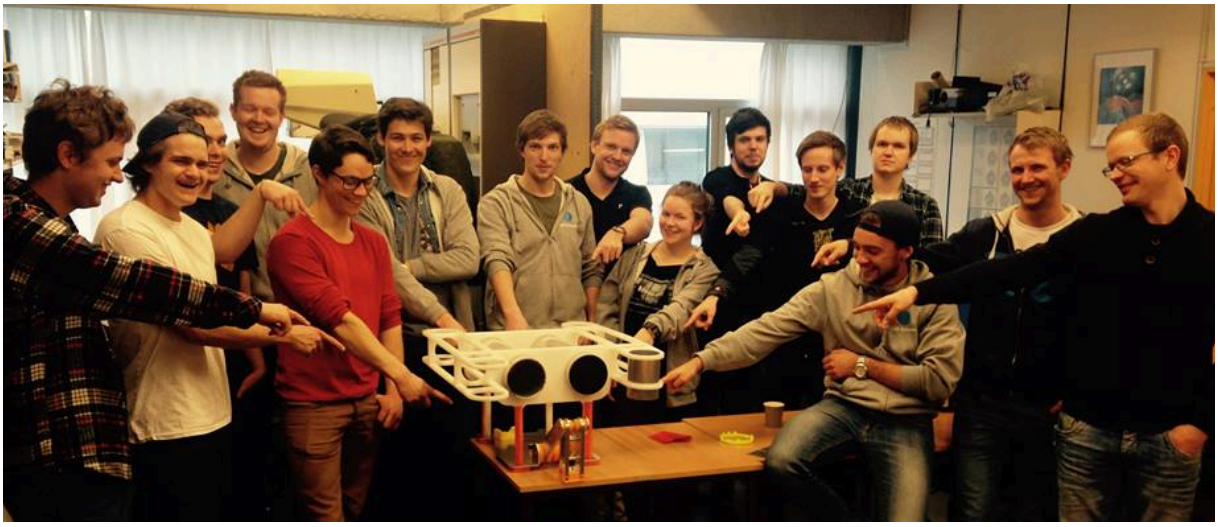


Figure 2: The 2015 UiS Subsea ROV team

Table of Contents

2 Design rationale

2015 is the second year UiS Subsea participates in the MATE ROV Competition. We have built a completely new vehicle, based on last year experiences, with a lot of adjustments and improvements. Due to the short time available (one semester) it was necessary to work in parallel on all the vessels components, and a good plan and management was crucial to finish in time.

Norway is known among the biggest contributors worldwide to technology within the oil and gas industry. Stavanger is considered as Norway's oil capitol and several international petroleum and subsea companies are headquartered here. The region possesses world-class subsea technology and experience, and a lot of companies have been eager to advise us when our plans of designing and building a new ROV were announced. Even with all the help and backup from the industry available we wanted to create and produce the majority of components and software ourselves, as one of our main goals is to be innovative and have a critical approach to the established solutions normally used in a ROV.

2.1 Planning and Design

With use of several different methods throughout the project, like a Milestone summary, Gant diagram, organizing-structure, Work breakdown structure (WBS) and Network diagrams, we could create a good overview of all the activities around the ROV project. Deadlines and important milestones where conducted in a milestone summary, which later was useful to develop the Gant chart. All activities around the ROV where conducted in a network chart where we could make all the work package's throughout the project.

As all the team members had very little experience with designing and developing a constructive ROV, we started out with an introduction meeting for a brainstorming to bring up all our ideas for the new ROV. This was organized in groups With an update of the lesson learned from last year, we decided the new ROV to be more sexier, more open, make it easier to access different components, easier to troubleshoot and make the software more flexible. Short time later Subsea 7 arranged a startup meeting with us to hear about our plans, and they were open for questioning and guidance. The team started the design process in January 2015 with gathering possible concepts for the design. When everyone had decided what concept they were going for, we could initiate the design of the frame. The Design went through several revisions because of updates and changes related to parts on the ROV. The frame had to be re-designed to incorporate all parts inside the structure.

The team started with a brainstorming process for all design concepts. These brainstorming processes where performed with the team divided into a mechanical, Data and electrical branch for organizational effectiveness. This was done so that the team members were able to participate in the concept decisions in the fields where they have their expertise. Since this project is ours we wanted to use a lot of the ideas that came up. Because the desire was to have a ROV we can feel ownership to.

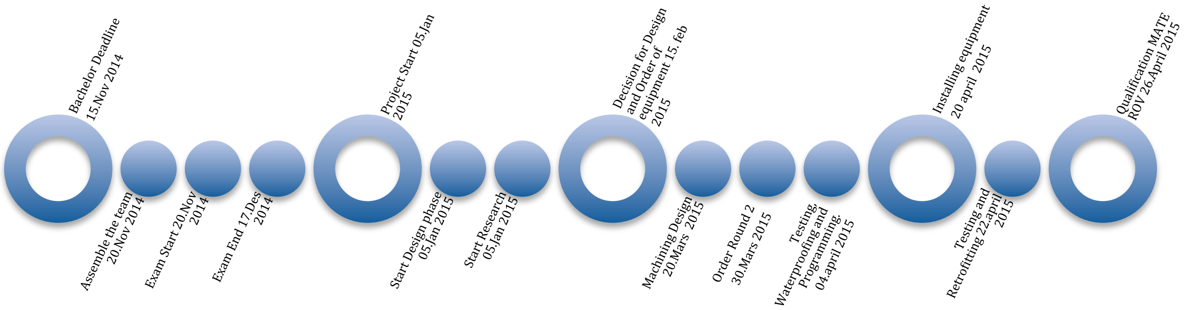


Figure 3: Milestones

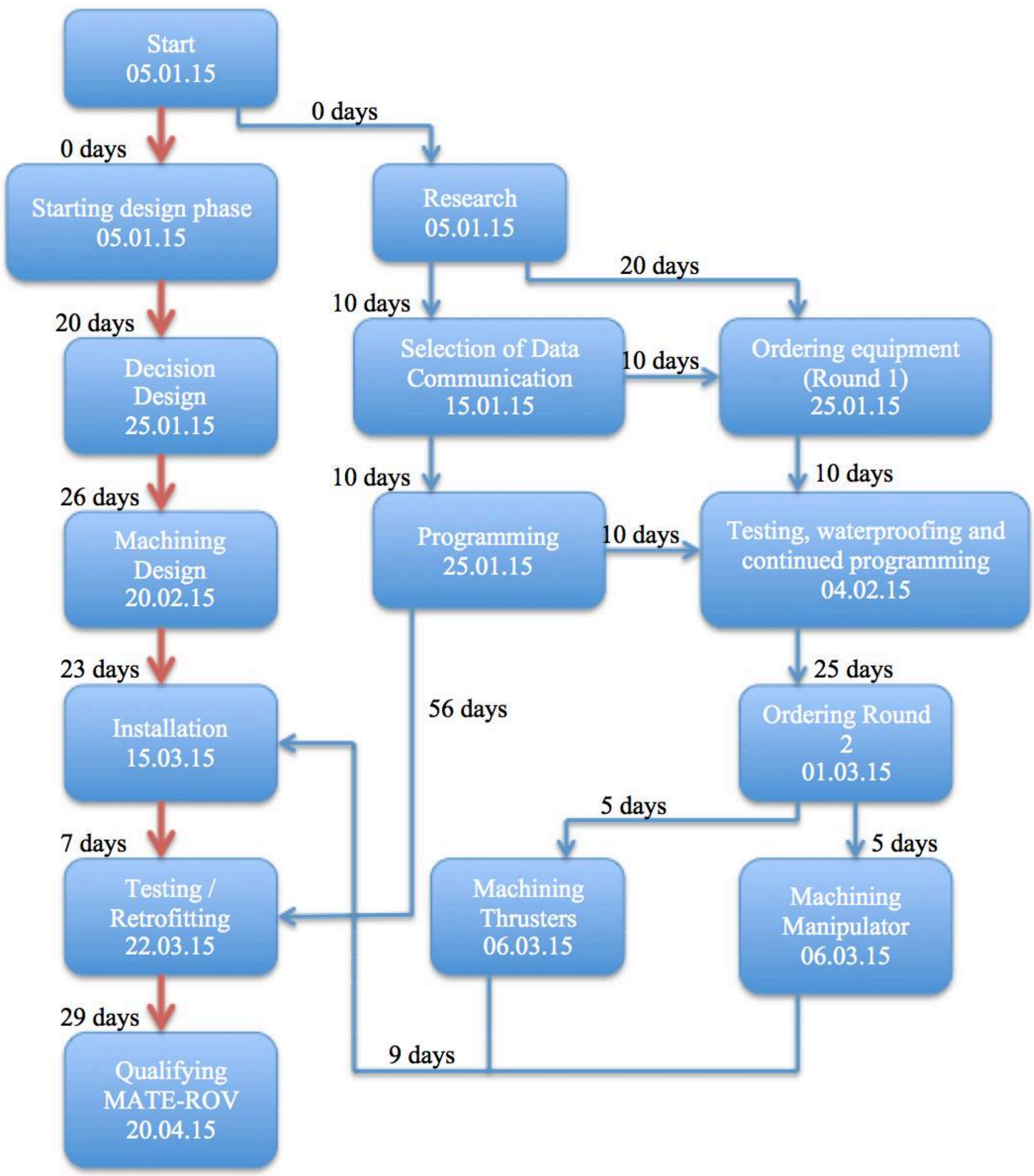


Figure 4: Network diagram

2.2 ROV Structure

The ROV framework is composed of 6 parts who are carved out from 12mm thick PEHD 1000. This material is highly ductile and has a density very similar to water, and will therefore behave neutral in water. The design has changed throughout the course of this project due to new components being added and changed from the original planes. The final product is designed and produced with compromises from the various parts of the ROV, e.g. the manipulator, thrusters and the PODs.

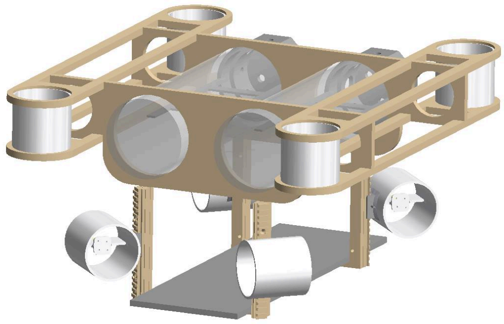


Figure 5: Final structure design of Thor

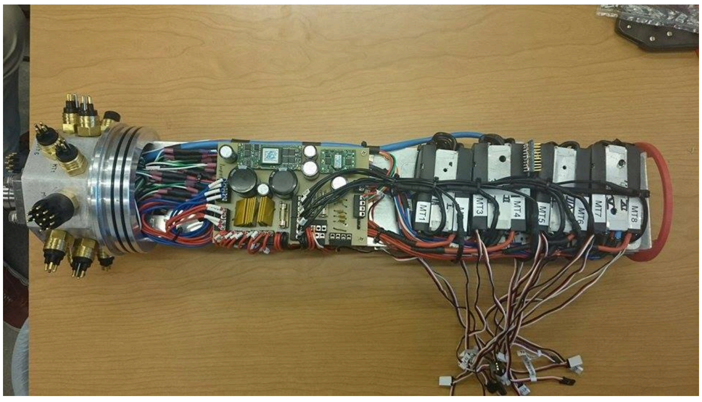
2.3 Buoyancy

The buoyancy calculations were done using CAD software Autodesk Inventor®. By assigning the proper material to all the components, the software will calculate point of gravity and volume of displaced water. Based on these models we attached floatation elements made from Divnycell H100 on various locations on the ROV to achieve the desired floating characteristics.

2.4 Electronics Housing

All electronics in the ROV are placed in two watertight housings (PODs). Noise generating components, such as motor controllers, are placed in one housing, while the noise sensitive components (e.g. microcontrollers) are placed in the other housing. The electrical housing has a cylindrical shape, with a plate of aluminium in the middle on which the components are placed. The end caps are manufactured from solid blocks of aluminium, and o-ring seals are used to keep them watertight.

The tether splits into two approximately 30 cm before the tether is connected to the ROV, so that the power cable can be directly mounted into the first housing and the communication cable to the second housing (containing noise sensitive components).



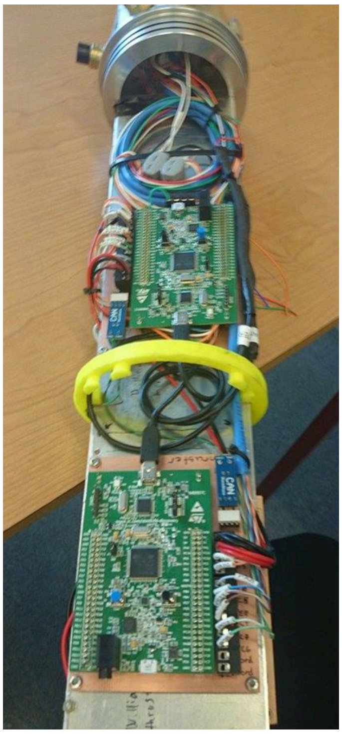


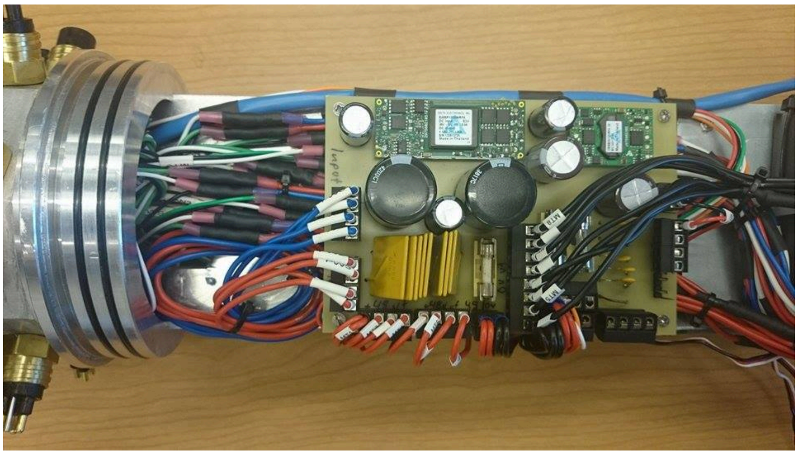
Figure 6 (left): POD 1, containing noise generating components

Figure 7 (right): POD 2, containing noise sensitive components

2.5 Power Distribution

This year's design has four voltage levels: 48V, 12V, 5V and 3.3V. The DC/DC converters gets power from the tether, converts the 48V to 12V and 5V, and distributes the converted power to the rest of the system. The laser (3.3V) is supplied through a STM32F4 GPIO pin.

As the majority of power consuming components are supplied through the 48V, there is no need for a big DC/DC converters. There are two DC/DC converters, which are small enough to be placed on a DIY PCB. Each DC/DC converter has capacitors on the input and output to help stabilize the current. This will minimize the chance of transients causing a short blackout on the system.



Figur 8: DC/DC power converter, made by UiS Subsea

2.6 Topside fuse

As specified in the rules, topside has a fuse box containing a 40A fuse. This is the same fuse box that was used by UIS Subsea in the 2014 ROV MATE Competition. This fuse box distributes the current over the four cord pairs in the power cable.

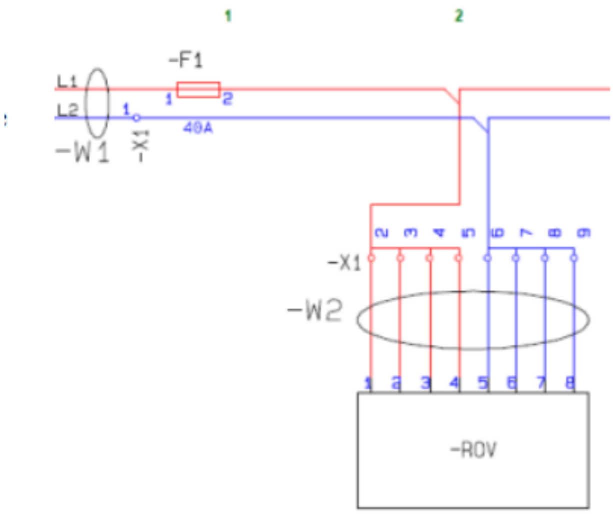


Figure 9: Circuit drawing, topside fuse

2.7 Thrusters

To avoid using a DC/DC converter to supply power to the thrusters we choose motors that can operate at the voltage as supplied from topside. The motors we choose was the 4112-320KV Turnigy Multistar 22 Pole Brushless which is ratet to operate at 33.6 V. Epoxy is used to isolate the stator from water so the motors can run without housings. As a result the motors are cooled directly by water, which allows us to run them at 48V without being damaged by overheating the coils. This has been stress tested in the laboratory and been concluded as successful. The aluminum thruster housing was designed and made in-house by the team.

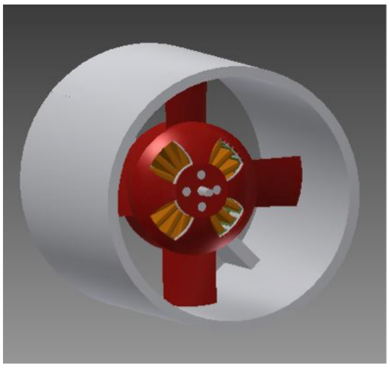


Figure 10: CAD-drawing of motor housing

Figure 11: Photo of final housings

Using the guidelines given by the MATE forum [2], we were able to successfully complete the epoxy process and receive values from 40-50M ohms from the meg-ohm meter on all eight motors, which is higher than the demand at 10M ohms, given by the MATE rules.
Video: meg-testing epoxy insulated thruster motors [3]

2.7.1 Propellers

To achieve the best-suited propellers we used thrust data given by our self made test station as shown in figure below:

This was to get the propeller with the best specification for use on "Tor". All off the propellers were designed by the team and manufactured using a Makerbot 3D-printer. By 3D printing propellers, we were able to reduce cost and therefore being able to produce a variety of propellers for testing and for spare.

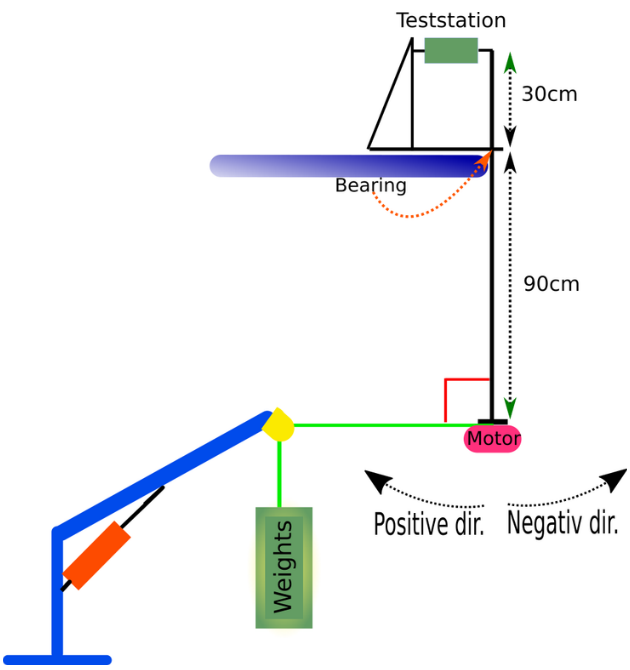


Figure 12: Model of test rig for propeller testing

2.7.2 Control system

For the type ROV to be used in MATE, where maneuvering is a given priority over speed and economical driving, intersection layout for the motors is the most prevalent, as given in the figure to the right.

To reduce the cost we choose to use the same motor controllers (OS OCA-170HV) as used in Njord (last year's ROV). These motor controllers have an operation voltage up to 50.4 V, which is desirable for our specifications. A microcontroller does the necessary calculations based on the signals received from the joystick and convert them to PWM signals that are used for each of the motor controllers.

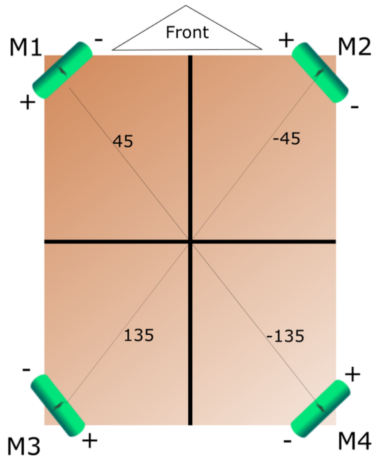


Figure 13: Showing layout of motors 1-4 (horisontal domain). 4 additional motors are placed in each corner to handle the vertical domain.

2.8 Manipulator

The manipulator has five functions including the claw. The joints move by using straps and the claw grips by pulling a wire. The main reason to use straps is to reduce the manipulators impact on the ROV's mass center, as the straps made it possible to mount the motors in the center of the ROV.

Six stepper motors operate the manipulator. This motor type is known for good precision and holding torque, which is useful for the control of a manipulator. As the various joints on the manipulator requires different holding torque the six motors are of different sizes.

To create the manipulator it has been used aluminum and plastic. Aluminium is used in the "arms" for a more solid construction, as well as in the motor housings. The claw and gears are made of 3D printed plastic.

To generate maximum torque to the claw, the stepper motor's rotor is connected to a threaded rod. When the rod rotates a nut moves up and down the threaded rod. The nut is connected to the wire for opening and closing of the claw.

Figure 14: Manipulator and ROV base platform with stepper motors mounted

2.9 Communication

Below is a complete circuit diagram of the communication and power lines in the ROV.

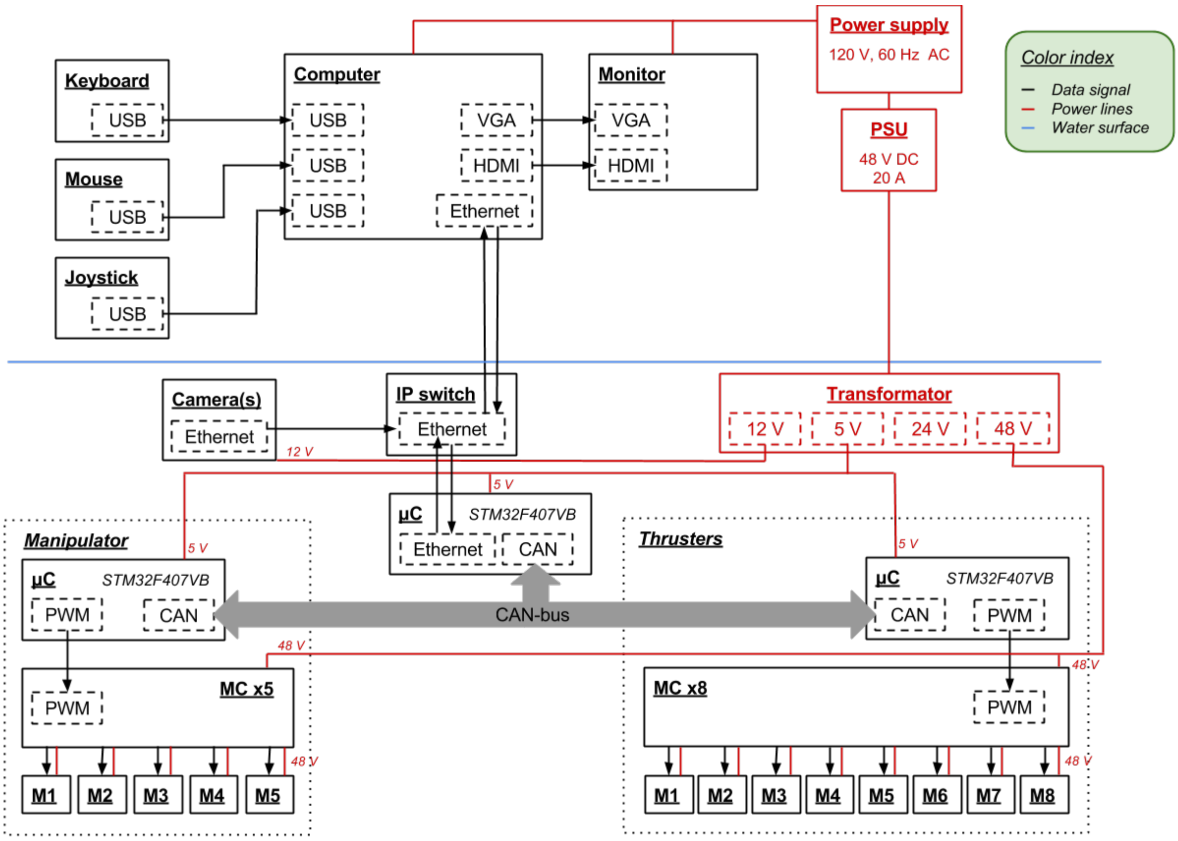


Figure 15: Communication and power lines

2.9.1 Tether

The tether used in this year's design is the same as the one used in UIS Subsea's last year's ROV *Njord*. The used tether was donated by Innova AS, and features standard Burton Subsea Connectors at the electrical housings. The tether consists of a power cable and a communication cable.

The power cable consists of 8x16 AWG cables, which means that three pairs can exclusively be used to supply the thrusters with power. This limits the noice impact on the rest of the ROV electrical system generated by the thrusters. The last pair of wires is used to power the rest of the electrical systems.

The communication cable is a cat. 5 ethernet cable with a data transfer capacity up to 1 Gb/s. The signals from the IP-cameras and the signals to/from the ROV are distributed through an Ethernet switch to avoid communication and overload problems.

2.9.2 *Internal*

The internal communication system in the ROV consists of three STM32F407VB microcontrollers (a main node, one for the manipulator and one for the thrusters) communicating together over CAN-bus. CAN-bus was chosen due to its flexibility (easy to add and remove nodes if necessary without any need of change in the code), it's ability of being noise resistant and minimum time delay as data can be hardware filtrated to the desired nodes.

2.10 *Software*

The topside control system establishes two-way communication between topside and the vessel. It intends to read user inputs (joystick(s) movements and events in the graphical user interface) and to display vehicle status and sensor data on the monitor(s). The application is written in Python, with PyQt4 and PySDL2 for GUI and joystick support. The software flow is event based, which means that vessel and sensor data is only put on the CAN-bus when requested topside, and maneuver data is only sent from topside when a joystick event is detected. This is realized by use of Qt's *signals & slots* features. The system flow is described in the flowcharts below:

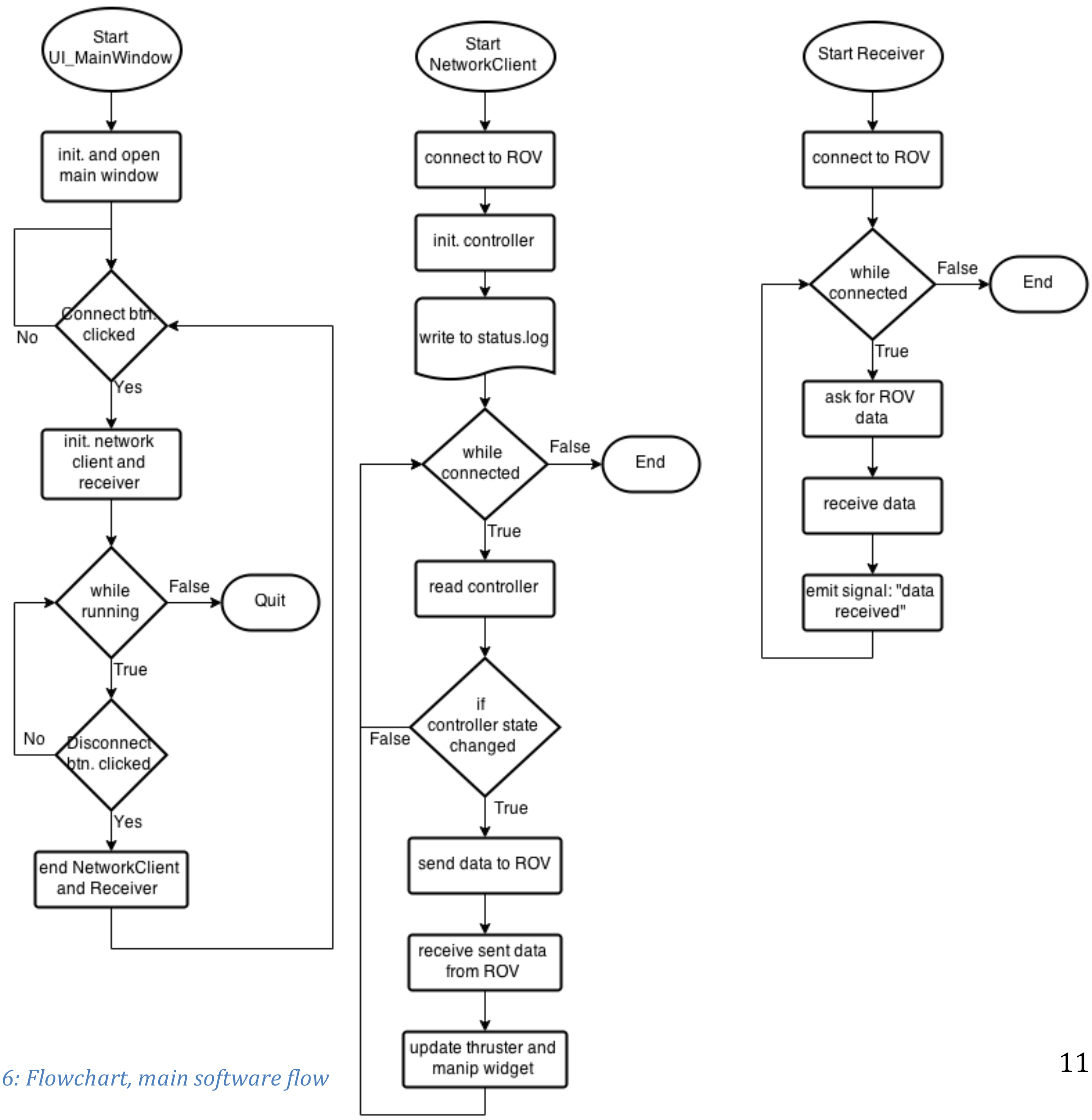


Figure 16: Flowchart, main software flow

A main focus in our GUI design is to keep the user in control and make the application as flexible and intuitive as possible. The user is self to decide which data and information that should be displayed on the monitor, whether one or more joysticks should be used and set the key bindings (default setting is given by start up). All three camera views can be displayed simultaneously or separate.

All vessel and sensor data are added to different sub windows that can be opened and closed after the users preferences as long as the main window runs. They are all implemented in the main windows *mdiArea (*an embedded Qt-function which add repositioning and docking features to sub windows) as sub windows. Each window runs on its own thread and will update as soon as a signal of new available data from the ROV is emitted (see: *data received*-box in lower right corner of the flow chart).

Displayed below is a screen shot of the main window in action. Remark that at the moment of the screen shot the ROV was doing a test run on land and therefore does it not show all the functions in action. But it should give an overview although.

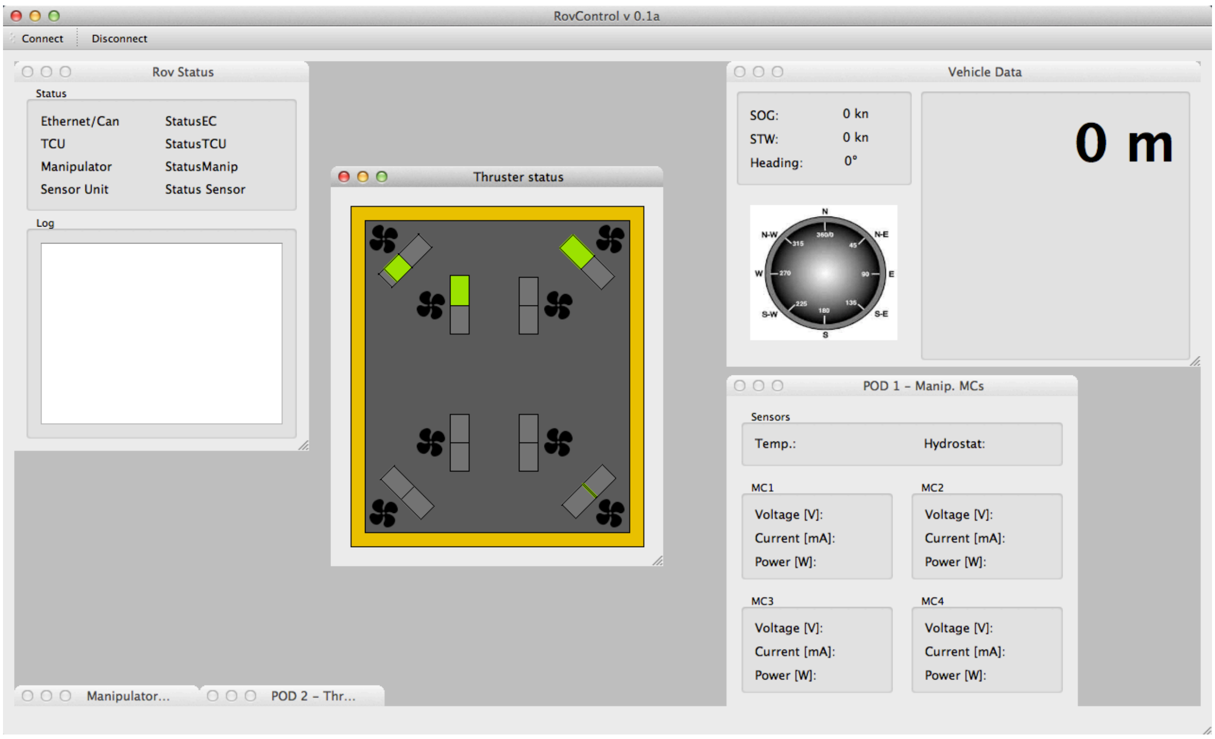


Figure 17: screenshot of main window of ROV program

2.11 Cameras

The ROV contains three cameras. Two mounted on the front, where one of them can rotate 90 degrees. This camera is designed to give the ROV-pilot good vision when "driving". To give the co-pilot a better point of view for manipulator tasks one camera is pointed toward the manipulator. The third camera is mounted on the back to enable visibility when the ROV is driving backwards.

The three cameras are all same models, Point Grey Blackfly GIGE. They transfer data through the ethernet cable in the tether from ROV to topside. Due to limited bandwidth, all cameras use the same resolution of 1280x960 with ~24 fps.
All cameras use the same lens, which is capable of wide angle viewing up to 100 degrees.

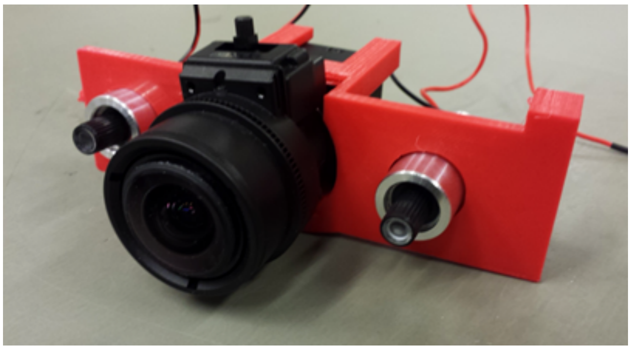


Figure 18: A Point Grey Blackfly GIGE IP camera. Here mounted to a 3D printed frame with lasers attached.

2.11.1 Measuring dimensions of objects

The measuring of dimensions is done by first measuring the distance towards the object. This is done by two lasers angling towards each other. When both lasers points towards a object the program detects the distance between the dots emitted from each laser. Then the software coordinates the middle of the dots, and calculates the distance between the dots. Then by comparing this distance with a previously calibrated function it is possible to calculate the length off the measured object. It is now possible to measure length between two mouse-clicks on the screen. The calculated distance gives a function that determines how many meters one pixel represent. By clicking on each end of the object, the program prints out the length. Later, the icebergs volume gets calculated by measuring its height and its diameter in that order.

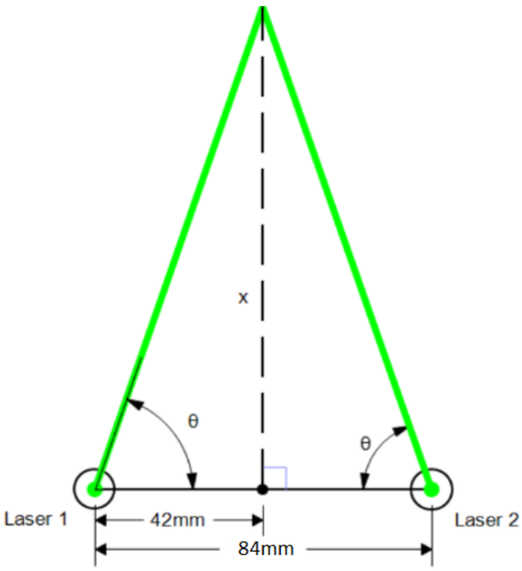


Figure 19: Angle of lasers and placement. X indicates the distance from the camera's point of view to the lasers's crossingpoint.

2.12 Lights

LED lights were chosen for illuminating the areas around the ROV. The LED-lights are supplied through 12V, and use 10W, with a lumen of 800. The lights were bought and dismantled, and put in watertight housings that was manufactured from a solid block of aluminium, with o-rings to prevent leakages. Aluminium was chosen due to its high heat transfer coefficient. This will lead away the excess heat the LED will generate, and will prevent it from overheating.

3 Safety

3.1 Philosophy

The Norwegian oil industry is known for high safety standards and extensive technical competence. For the 2015 competition we have emphasized this mind set and enforced the policies in all aspects of our work, whether it is mechanical or electrical. UiS Subsea is a student organization focused on working as an engineer would in the oil industry. It is therefore important for us to work in a similar type of environment. Enforcing healthy safety-routines such as equipping protective gear when working on the ROV has been an important part of the development process. This was particularly important during the testing phase, when we were working with electronics, near water.

3.2 Mechanical safety

This year we expanded our team of mechanical engineering students, and had a total of five mechanical engineering students working on our five function manipulator. We had one mechanical engineering student who designed the frame of the ROV and two mechanical engineering students who designed the eight thruster houses powering the ROV. On the manipulator we designed motor holders, which have been designed for tight fit and secure placement of the motors. The wire which operate the gripping mechanism have been tightly fitted to the manipulator, and critical parts have been covered, to minimize the risk of someone getting hurt by the moving parts of the manipulator.

3.3 Electrical safety

The system has separate fuses for each motor and for all outputs from the main power unit. If the system does not receive acceptable data from the topside controller, the system stops all moving parts immediately. To protect electric components we also have a very high focus on ensuring that the O-ring seals for the electrical pods, and electric motors have no damage. The thruster motors have been dipped in epoxy, to ensure that no water gets in contact with electrical components of the motors.

3.4 Operational safety

During the process of preparing the ROV for an operation we use a safety checklist, to ensure that all precautionary steps are taken, which are necessary for safe operation. Using this checklist prevents danger to personnel and equipment and helps increase the probability for a successful operation. Before lifting the ROV into the water the team makes sure to keep all hands away from the thrusters. Once the ROV is safely in the water, the person responsible for the operation gives the signal “Clear”, which indicates that the pilot is free to operate the ROV and start the mission.

4 Challenges, troubleshooting and lessons learned

Technical

As it was necessary to have the camera and lasers rotating on the same axis as a result they both had to be inside the camera housing, where the maximum distance between the lasers is relatively small. Due to the small distance between the lasers, the laser beams could not be directed parallel from one another. From the viewpoint of the ROV, the change in pixels at different ranges would not give an accurate enough measurement with our setup. The solution for this problem was to get the lasers to point towards each other. The crossing point indicates max distance measurement range. Because the lasers are pointing towards each other the calibration curve becomes non-linear. The trend line for the calibration curve fits best with a power function. This produces a lot of measurement errors. To reduce measurement errors the table used in the calibration are split in two, and differentiated in the program code.

One lesson learned from a Technical challenge was that the best way to attack a problem is to divide it into different phases, and identify a minimum scope of what had to be done in order to get a functional part/software. And add "nice to have" extra features after production of a functional part/ software. This way you kept the focus on the critical phases of the process, and reduced the risk of delays.

Interpersonal

From UIS Subsea was established in 2013 the organization have grown substantially over the last year, from 14 persons I 2013 to more than 50 people in 2014. It is a positive thing that so many students share the common interest in building ROVs and AUVs and wants to contribute to the organization. The back side of this growth from a small organization to a middle size one is that's it's no longer sufficient to just do modifications, or communicate verbally and expect the messages to reach every person in the organization. Therefor we divided our self into small teams with team leaders who among other things also where responsible for communication with the other groups and the management team. We also early on established a formality that all discussions and conclusions that affected other group's scope of work had to be discussed in UIS Subsea's forum. This way everyone who wanted to contribute in the problem solving could easily participate and catch up on previous discussions and conclusions.

We learned in this process that in order for this system to work everyone has to be loyal to the systems. When things were a bit hectic it could sometimes be tempting to postpone updating the forum, which lead to other conclusions were being made from the wrong assumptions. So one major lesson learned through the project is the importance to always assure that the critical information reach every person in the organization, at least the ones affected by the decision.

5 Future Improvements

To futher improve the handling of the ROV when maneuvering in the horizontal domain we wanted to implement PID regulations to avoid the vessel from drifting (based on data from sea currents). If this feature was integrated the ROV would have a much more predictable behavior as the ROV would stop moving (refered to the ground) when the joystick is not being operated by the pilot.

6 Budget

Below is given a overview over the 2015 ROV prosject:

Thruster	Budget	Description
Description	Estimate USD	
Motors	910	purchased
Motor Controller	910	Re-used from last years ROV
Sensor	130	purchased
Material	650	purchased
Connectors	3 900	Donated
Sum	6 500	
Sum - (reused parts + donations)	1 690	

Manipulator		
Description	Estimate USD	
Motors	910	purchased
Motor Controller	780	purchased
Sensor	260	purchased
Material	910	purchased
Machining bottom plate	910	Donated
Connectors	3 250	Donated
Sum	7 020	
Sum - (reused parts + donations)	2 860	

Camera		
Description	Estimate USD	
Camera	780	2/3 purchased 1/3 donated
Sensor	130	purchased
Connectors	1 950	Donated
Sum	2 860	
Sum - (reused parts + donations)	650	

Power Distribution

Description	Estimate USD	
Converter	390	purchased
Lys	195	purchased
Cable	390	Donated, Re-used from last years ROV
Other	260	purchased
Connectors	1 300	Donated
Sum	2 535	
Sum - (reused parts + donations)	845	

Communication

Description	Estimate USD	
Microcontroller	130	purchased
Sensor	130	purchased
Cable	390	Donated, Re-used from last years ROV
other	65	purchased
Sum	715	
Sum - (reused parts + donations)	325	

Software

Description	Estimate USD	
Top side computer	320	Donated
Joystick	130	purchased
Software Licenses	260	purchased
Sum	710	
Sum - (reused parts + donations)	390	

Production costs

Description	Estimate USD	
PEHD 1000	260	Re-used from last years ROV
POM	325	purchased
Aluminium	520	purchased
Other materials	390	purchased
Tools	1 300	Bought for this year ROV and future project
Attach Materials	520	purchased
Connectors	4 940	Donated
Sum	8 255	
Sum - (reused parts + donations)	3 055	

Travel costs

Description	Estimate USD	
Deductible, travel	-6 760	purchased
Flights	19 500	purchased
Hotel	4 550	purchased

Food, competition	650	purchased
Transportation Expenses	1 300	purchased
Shipping, ROV	1 300	purchased
Sum	20 540	

Total estimated costs

Description	Estimate USD	
Total costs	49 135	
Total value of donations/reuse	18 780	
Total costs - donations/reuse	30 355	

As you can see there is an estimated cost of approx. 30.400 USD. The ROV team at UiS Subsea have already received economical support from the university at NOK 200.000 (≈25.000 USD) and we are still expecting some founds to our account from different sponsor. Predicted costs are set to 0 USD with the travel deductible included.

7 Acknowledgements

UiS Subsea would like to thank the following companies and persons for their donations, expertise, support and knowledge shared with us. We really appreciate their contribution, without them there would be impossible to realize *Thor.*

MATE Center	For hosting the competition.
The University of Stavanger	Provides funds, materials and laboratory spaces.
Oceaneering	Provides funds and technical expertise
Subsea 7	Provides funds and technical expertise
Innova AS	Tether and technical expertise
MacArtney	Provides us with connectors, and technical Expertise.
Kystdesign	Provides us with funds
FFU	Provides us with funds
DeepOcean	Provides us with funds
Stinger	Provides us with funds
Gassco	Provides us with funds
ElfaDistrelec	Provides us with discount for equipment
Smed T. Kristiansen AS	Water jet cutting of components
JBM Products	Water jet cutting and bending of components
IKM Subsea	For technical expertise

Professor Arnfinn Nergård, Professor Hirpa G. Lemu and Professor Morten Tengesdal for providing us with technical expertise and advice during the development of our ROV.

8 References

[1] http://no.wikipedia.org/wiki/Tor

[2] http://forums.marinetech2.org/viewtopic.php?f=21&t=237

[3] https://www.youtube.com/watch?v=zgE7Fu5T4CY

NB! All photos, videos, figures, diagrams and flowcharts in this tech. report are taken/drawn/created by members of UiS Subsea's 2015 ROV Team.

20

9 Safety Checklist

1. Safety glasses ON
2. Check that main fuse is set to OFF before working on ROV.
3. Is the tether securely connected and untangled?
4. Are all connectors attached and no wires are exposed.
5. Ensure all thrusters and propellers are securely fastened.
6. Ensure all propeller guards are in place.
7. Make sure electronics housings are tight and secured.
8. All personnel clear of ROV.
9. Main fuse ON
10. Test controller inputs and propeller rotation.
11. Pilot hands clear of controllers
12. Is tether management ready?
13. Lift ROV into the water.
14. Check for possible leaks while lowering the ROV slowly into the water.
15. Wait until all personnel are clear of the ROV before giving the GO for the pilot to start maneuvering.

10 Wiring diagrams

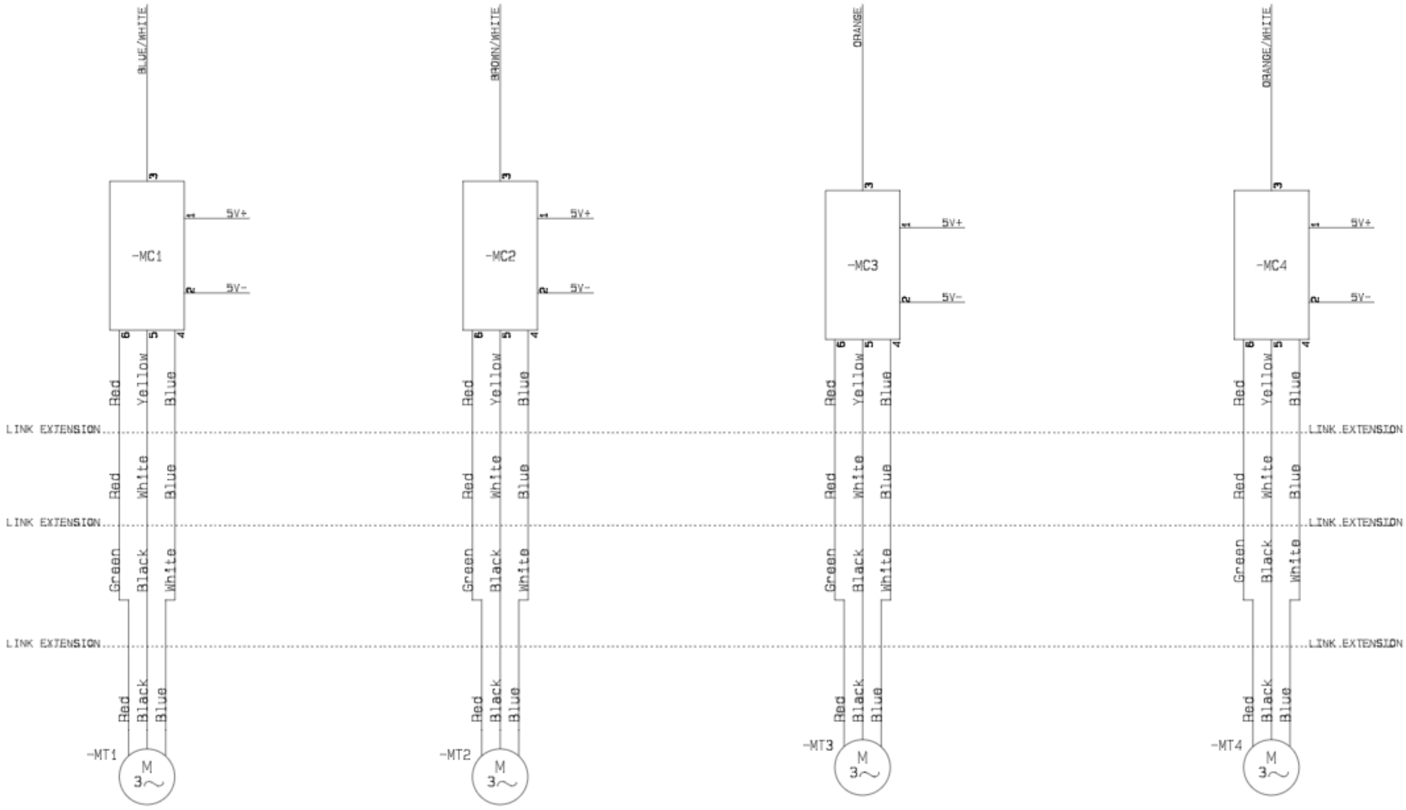


Figure 20: Thrusters 1-4, horisontal domain

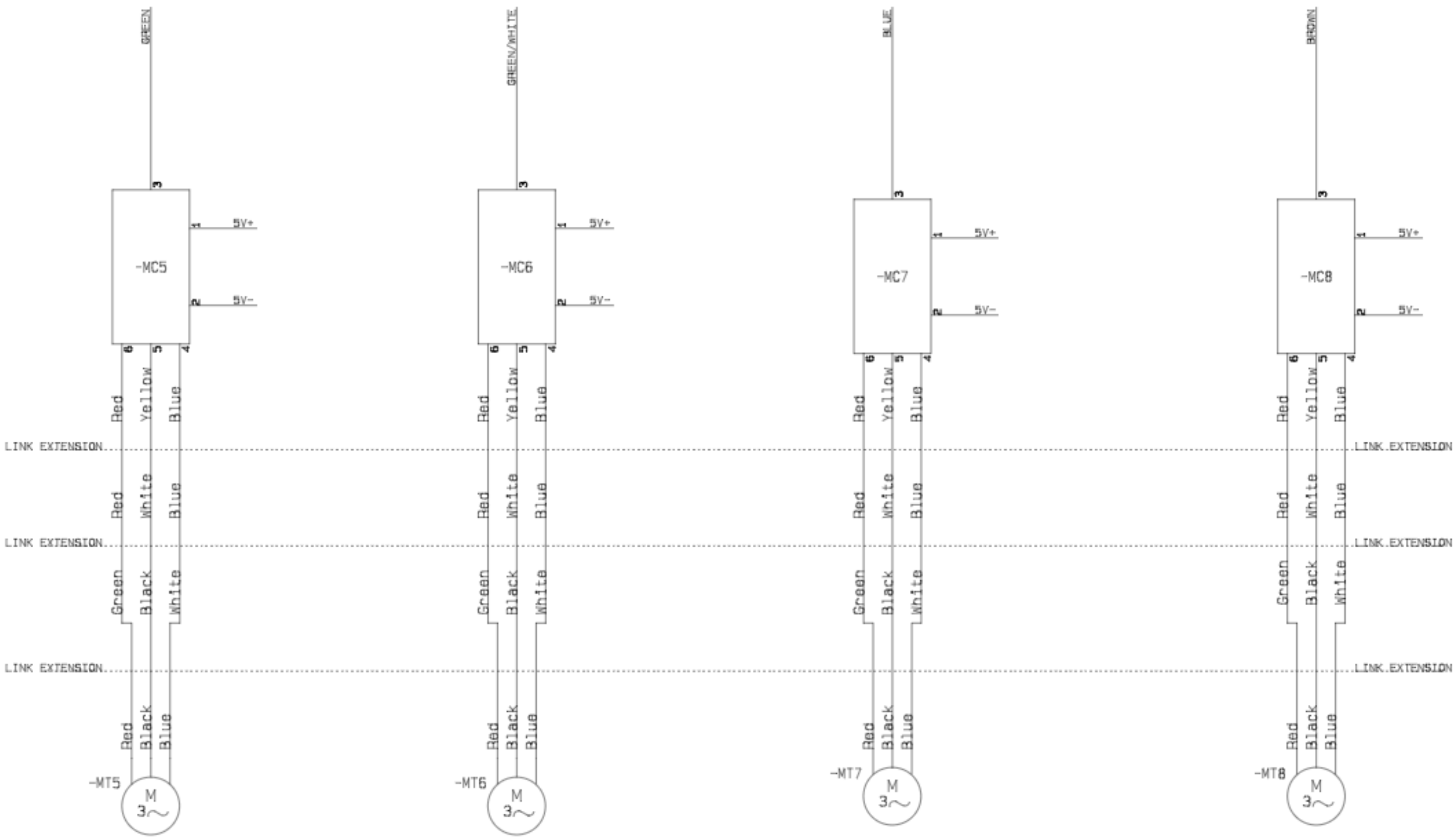


Figure 21: Thrusters 5-8, vertical domain

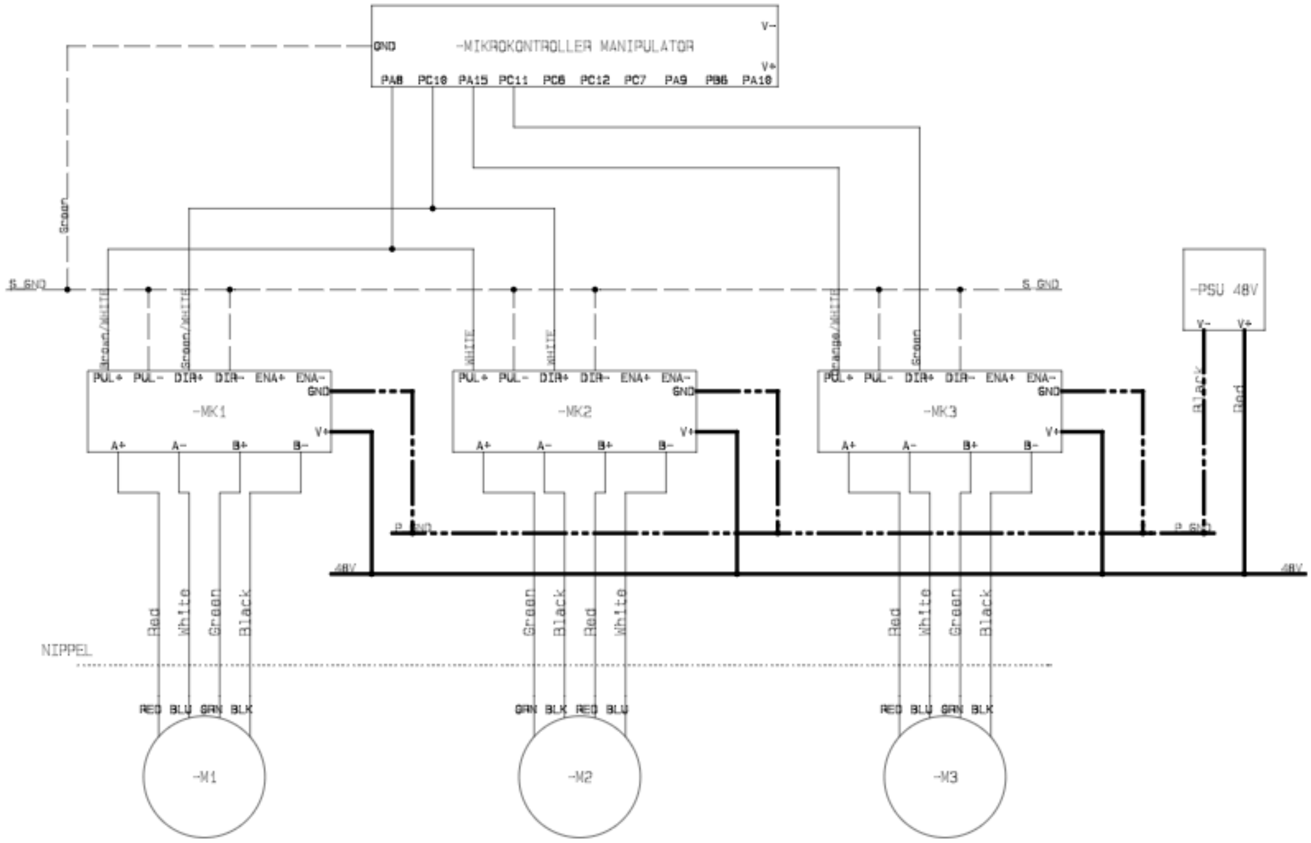


Figure 22: Manipulator, 48 V (motors 1-3)

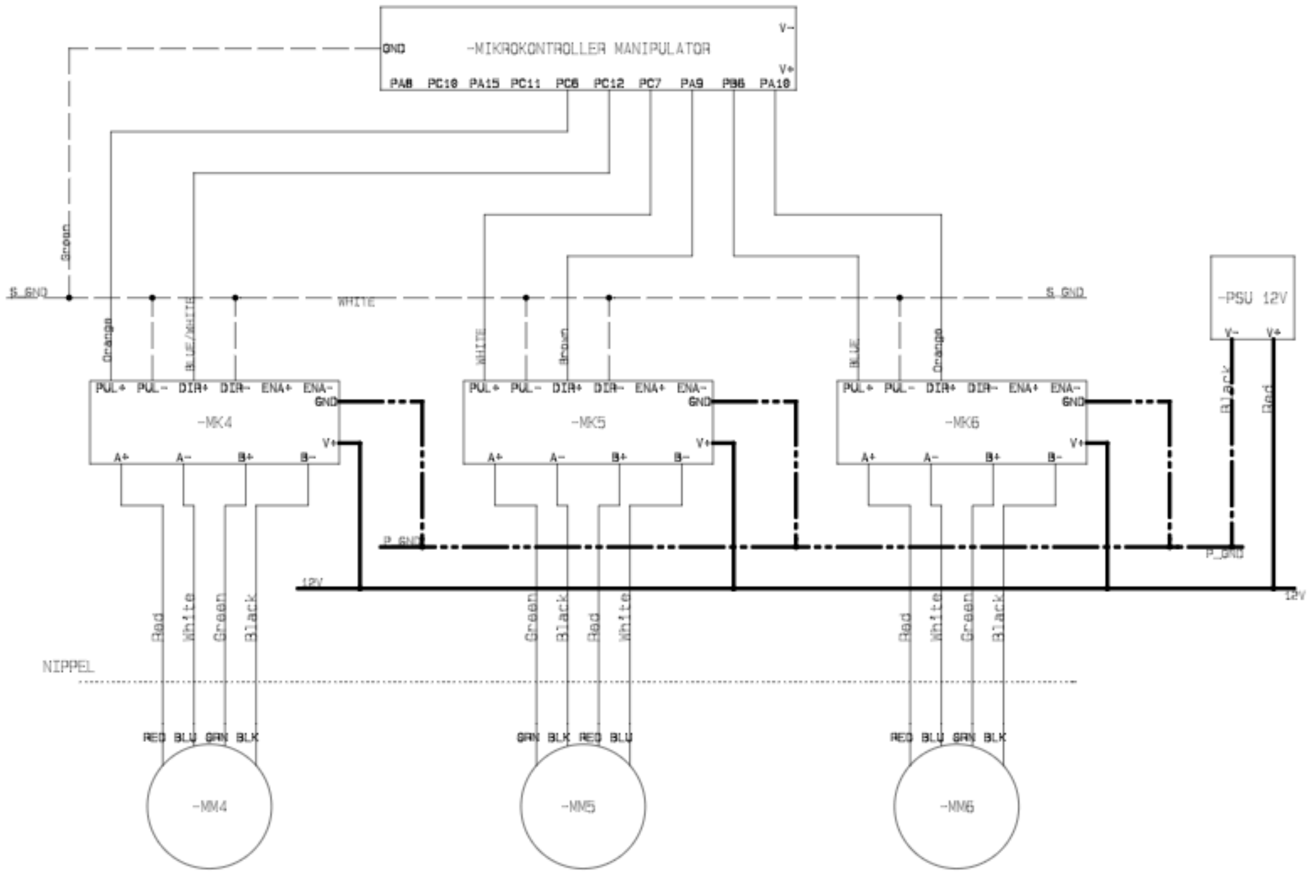


Figure 23: Manipulator, 12 V