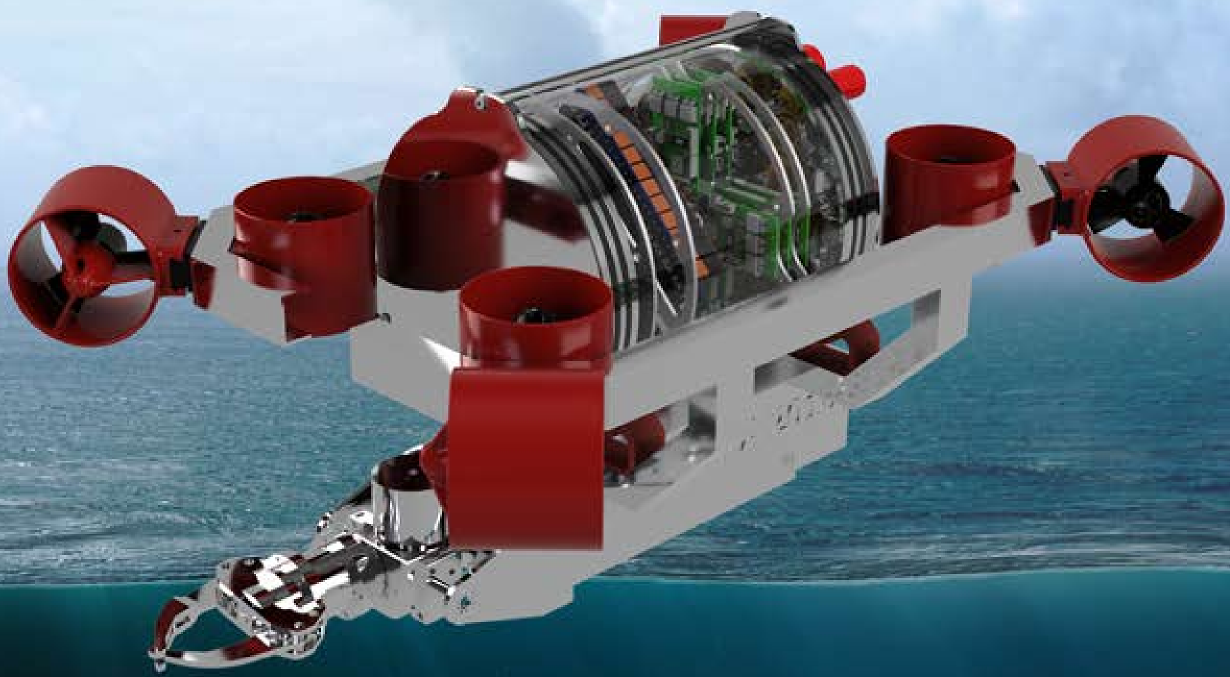
ÆGIR ROV



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1 Introduction

1.1 Abstract

UiS Subsea's newest addition, *Ægir*, is a purpose-built underwater vehicle designed to perform challenging tasks in both inner- and outer space exploration. As such, *Ægir* is very small and light weight. In the 2016 MATE ROV Competition, the company will demonstrate *Ægir*'s ability to do a selection of tasks in a timely and reliable manner. The competition is set to simulate the hostile environments found on Jupiter's moon, Europa; as well as the depths of the Gulf of Mexico. As a result, the company has been put through real challenges and obstructions in designing and constructing the vehicle. The main goal for UiS Subsea, as a company, is to provide an environment where students can gain experience as subsea engineers. Therefore, participating in the MATE ROV Competition is a great way to combine theory and practice to achieve a common goal. By solving these challenges, UiS Subsea believes that the aforementioned goal is achieved. This year's ROV-team consist of 15 bachelor students from mechanical-, electrical- and computer engineering studies. The team which will be traveling to NASA's Neutral Buoyancy Lab, consist of 14 of the previously mentioned bachelor students along with two second year students. Since the project started in January, all fields of studies worked together to accomplish the goals set for the project. The ambitions are high for the MATE ROV Competition and we are excited to participate with this year's ROV, *Ægir*.

Figure 1.1: *The 2016 UiS Subsea ROV team.*

1.2 Acknowledgements

We are grateful for the support and funding given to UiS Subsea from the University of Stavanger and its institutes in the Faculty of Science and Technology. Thank you Hirpa G. Lemu, Morten Tengesdal, Terje Kaarstad and R.M. Chandima Ratnayake for supervising the bachelor theses at the 2016 ROV team.

Without our sponsors in the industry, UiS Subsea would not exist. Thank you for having faith in our work and seeing the value of this project. A special thanks to the MATE Center for hosting the competition at NASA's Neutral Buoyancy Lab.

MATE Center	Competition Host
The University of Stavanger	Funding, materials, equipment and lab space
FFU	Funding and expertise
Oceaneering	Funding and expertise
Subsea 7	Funding and expertise
MacArtney	Equipment (connectors) and expertise
Elfa Distrelec	Equipment (discounts) and expertise
Envirex	Funding and expertise
Gassco	Funding and expertise
Deepocean	Funding and expertise
Smed T. Kristiansen AS	Water jet cutting and expertise
Stinger	Funding and expertise
SKF	Equipment (bearings) and expertise
Innova AS	Equipment and expertise
Statoil	Funding

Figure 1.2: *Sponsors of the 2016 UiS Subsea ROV project.*

Contents

2 Design rationale

2.1 Design process

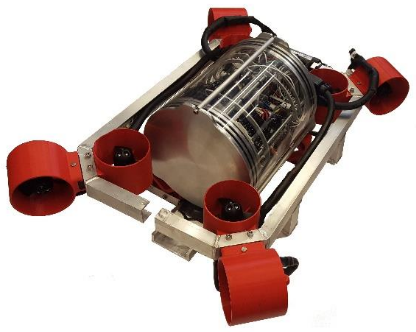

Figure 2.1: *Ægir*.

The company began the product development phase with identifying where there was room for improvement from our previously made ROVs along with future goals for *Ægir*. After the mission specification was released, the concept development phase was started by identifying the requirements for the mission. The main defining factor in the concept development phase was the new size and weight restrictions, forcing the company to think thoroughly about the weight and volume of each component.

With the requirements and target specifications defined, many different concepts were generated in order to find the best solution. Some concepts were rejected due to not meeting the requirements. The remaining concepts were then included in a concept scoring matrix, scoring the concepts from 1-5 with respect to the requirements. The scores were added, and the best concept was selected for further development. With the help of CAD-tools and FEA-simulations, both the concept generation and product development went quickly.

The company decided before the concept generation stage that *Ægir* would only have one electronics housing, with the dimensions defined immediately. This approach gave the team a constant to design the ROV around, both on the inside and the outside. Doing this also enabled the different parts of the team to work in parallel, ensuring rapid development. The transition to one housing, instead of two and three as on previous ROVs, required that special precautions were taken in regards to electromagnetic interference. To minimize this problem, the placement of circuit boards and connectors had to be done in such a way as to separate high and low power electronics as much as possible. In return, the solution required fewer connectors and less total volume; which in turn reduced production cost.

2.2 Frame

The shape of the frame is built around the electronics housing and the thrusters. Having the thrusters far from the center gives better maneuverability and provides sufficient torque when the ROV has eccentric loads. The increased torque along with a electronics housing in the center makes the frame ideal for the 6 Degrees of Freedom(DOF) navigation system.

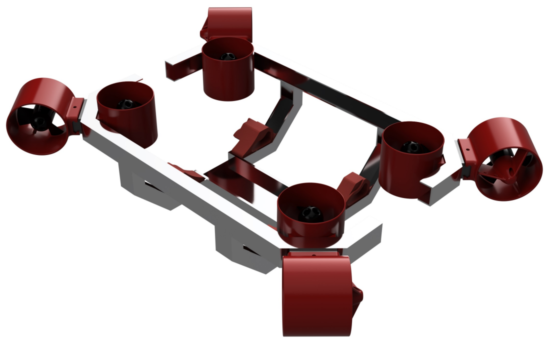

Figure 2.2: *Ægir's frame.*

Frame-mounted lighting

The headlights are potted in optically clear epoxy, using a mold made from aluminum to mount the headlights in place. This solution requires minimal space and weight and offers a large improvement from previous designs.

2.3 Electronics housing

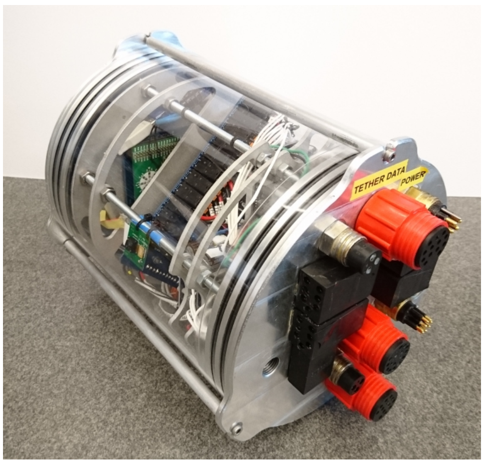

Figure 2.3: *The electronics housing on Ægir.*

The electronics housing is constructed from two aluminum end-caps, with an acrylic tube between them. An advantage of using acrylic tube is that one can visually inspect the O-rings, and also the electronics via status indicator LED's. The end-caps are CNC milled with three "wings" so that the end-caps will be held in place by three rods,in case the air volume in the housing expands due to heat. The rods also prevents the housing from rotating within the frame. Due to the low weight of the ROV, the housing doubles as the primary buoyancy. *Ægir*'s frame is constructed with aluminum u-channels, due to their low weight, low cost, availability and easy processing. The u-channels, used for the structure, provides excellent rigidity and possibility for modifying the frame as needed.

2.4 Power distribution

The power in *Ægir* is distributed via a circuit board specifically designed for this ROV. The inlet cable is connected to the board and main fuse 17 cm from the power supply attachment point. The inlet power is converted to 5 and 12 Volt via 3 DC/DC converters, and all subsystems have individual fuses. The fuse for each component is calculated after the components maximum current draw.

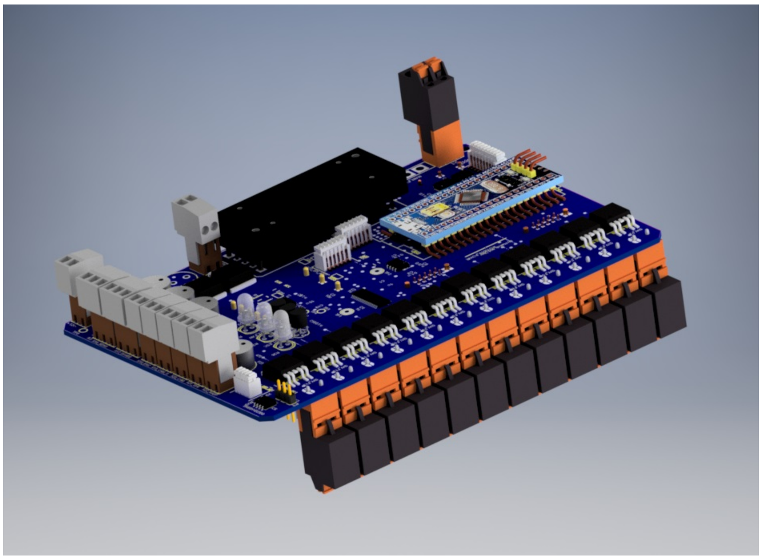

Figure 2.4: *Power distribution circuit board (CAD).*

Power and fuse calculation				
Component	Number	Voltage	Power	Fuse size
Motors, thruster	8	12 V	130 W	12 A
Motors, manipulator	4	12 V	130 W	12 A
Max total motor power is limited to 800 W in firmware			800 W	
LED working light	2	12 V	6 W	1.5 A
Circulation fan	1	12 V	8 W	2.5 A
Camera	1	12 V	5 W	1.0 A
Sensors	1	12 V	10 W	1.25 A
Interface circuit boards	1	5 V	10 W	3.5 A
Raspberry Pi	1	5 V	10 W	3.0 A
Camera servo	1	5 V	5 W	1.5 A
Ethernet switch	1	5 V	7 W	3.0 A
Manipulator encoders	2	5 V	0.6 W	0.5 A
Power loss in DC/DC converters			859/0.9 - 859 = 95 W	
Main fuse	1	48	954 W	30 A

Table 2.1: *Overview over the different fuses used for subsystems in Ægir.*

Main fuse dimensioning

$$Main\ fuse = ROV\ Max\ Load\ Current * 150\%$$

$$Main\ fuse = \frac{P_{max}}{V_{inlet}} * 1.5$$

$$Main\ fuse = \frac{954}{48} * 1.5 = 29.8A$$

The main fuse is chosen to the closest standard size, 30 A. The fuse is a slow blow type.

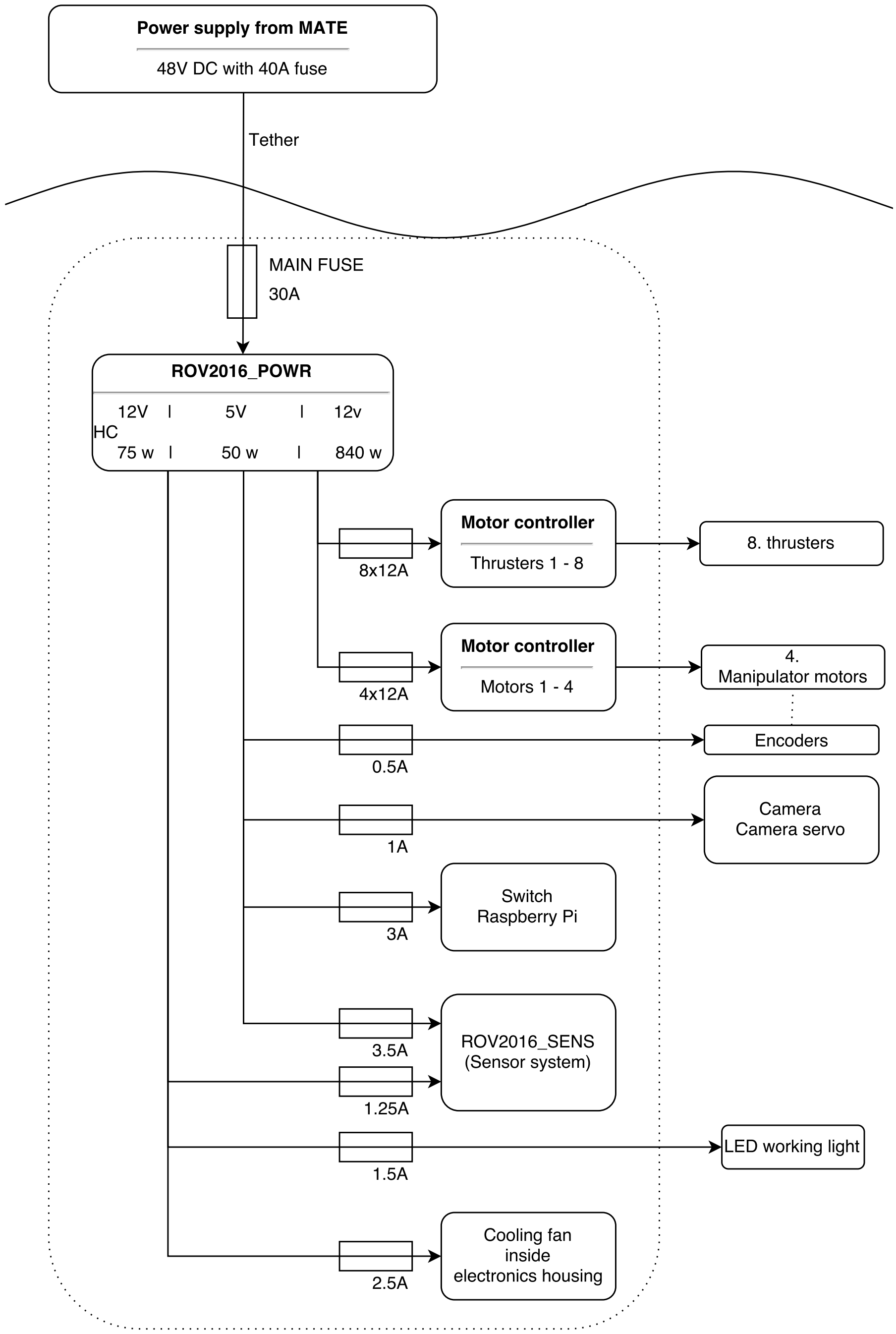

Figure 2.5: *Power distribution System Interconnect Diagram(SID).*

2.5 Tether

Ægir's tether contains power and communication cables neatly bundled into a flexible, protective sleeve with strain relief on both ends. The tether contains:

- $2*2.5mm^2$ flexible single stranded tinned core for power transfer. The power cables are sized for minimal weight and are calculated to be sufficient for the maximal power needed by *Ægir*. Maximum voltage drop over the 24 meter tether is calculated to a maximum of ≈ 6.7 V, which means the minimal operating voltage will be 41.3 V assuming the nominal 48 V from the power supply. The cut-off voltage of the on-board power converters is 36 V, [1], [5] and [2], which gives us a 5.3 V margin for fluctuations and/or inaccuracies in the power supply.
- CAT5e UTP flexible patch cord for Ethernet communication to the IP-camera. CAT5e was chosen due to its cost, flexibility and ability to transfer data with a bandwidth of Gbit/sec; which was necessary for streaming the IP-camera video feed.
- $2*24$ AWG for CAN-bus communication; calculated from bus length and number of nodes [3].

2.6 Propulsion

Thruster positioning

As seen in Figure 2.2, both the vertical and horizontal thrusters are mounted on the corners of the frame, with the vertical mounted on the inside and the horizontal on the outside of the frame. In addition, the horizontal thrusters are mounted at 45 degrees, to make it easier to realize 6-DOF.

Thruster shrouding

Figure 2.6: *Exploded view of thruster and shrouding (CAD).*

The shroud was first tested and used on the UiS Subsea's AUV. The shroud is produced using the additive manufacturing process known as fused deposition modeling(FDM). Due to the fact that the team had virtually unlimited access to this process through the university's 3D-printer, the shrouds were cost-effective and easily produced. The shrouds had a total length of 7.2 cm, with the propeller blade spanning 1 cm in the thruster length direction. With this, the safety requirement of 2 cm shrouding on both sides of the propeller was met [4].

Detachable thrusters

Given *Ægir*'s design, the horizontal thrusters led to the largest diameter exceeding the 58 cm diameter limit [4]. To meet this issue, picatinny rails were implemented into the thruster system design. These rails, which are typically used for military applications, allows for quick detachment and reattachment of objects that have a picatinny rail grove on them. Within the five minutes allowed after initial inspection, the thruster system can be quickly and efficiently attached to the outermost sides of the ROV. The thrusters will then be locked into position using clevis pins.

Propeller design

In order to create efficient, reliable and secure propellers, different propeller parameters, such as the number of blades and the blade angle, were tested and compared. These parameter sets were tested in a repeatable and reliable testing environment. A rig consisting of a straight pendulum, load cell, and base, was designed and produced to be able to test the thrust of each propeller parameter set. After a suitable propeller design was selected, the design was set out to a local 3D-solutions company to be manufactured using Multi-Jet Modeling(MJM). The propellers were a lot stiffer and had a smoother surface finish. Using this process, a propeller would see a 15% increase in thrust jumping from FDM to MJM. The optimal parameter combination was discovered to be an inner blade angle of 50 degrees with 3 propeller blades.

Motors

All eight thrusters use commercially bought DC-motors. The choice of motors were made after extensive testing of different models and working principles. The chosen motor, Series 28-30A from *NTM Prop Drive*, proved to give more thrust at a relatively low power consumption. Each thruster is able to produce a maximum of 34 N. At maximum thrust, the motor draws 20 A at 12 V. To avoid overloading the DC/DC-converter, software sets a hard limit to 50% of the maximum possible thrust. This gives the thrusters a practical maximum operating thrust of 18 N, drawing approximately 5.5 A.

Thruster insulation

Since these thrusters are self-made, measures must be taken to electrically isolate the stators and copper winding in the motors. This was done by making an aluminum mold where the stator was placed and then filled with epoxy. The mold was then put in a sealed container with a vacuum pump to remove air pockets in the mold and in the epoxy itself. After this processes it was left in an oven to cure. An insulation test showed that after soaking in water for 24 hours, the motor was still giving a resistance of over 100 $M\Omega$ at 250 V DC testing with a MegOhm meter. This indicates that the insulation process was successful.

Figure 2.7: *Insulated stator.*

2.7 Manipulator

The manipulator was designed with focus on weight, durability and modularity. To save weight, the manipulator and end effector is powered by 4 brushless DC motors potted in epoxy. This solution avoids the need for waterproof housings, but introduces the need for gearing as the RPM of the motors is relatively high. The gearing is realized using Delrin gears and lead screws. The manipulator system has four functions; a telescopic arm, a wrist with pitch and roll and an end effector equipped with an intermeshing gripper. The different functions can be locked in place manually in the event of failure. Grip and linear extension is controlled by force readings in the end positions. Wrist pitch and roll is controlled using magnetic absolute encoders to read the position. The manipulator is controlled by the surface control system.

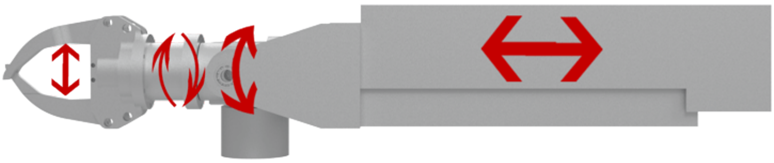

Figure 2.8: *Manipulator showing the different degrees of freedom (CAD).*

2.8 Camera system

Ægir's camera system consists of three cameras: the main camera, a rear-view camera and a camera mounted inside the electronics housing. Video streams can be started/stopped via buttons in the graphical user interface. There are also buttons to grab still images for each camera. It is also possible to play audio from the rear-view camera's microphones. The audio feedback helps the operator in navigating the vessel by relaying the thruster power in an intuitive way.

Main camera

The main camera is mounted at the front, and is the operators main view for navigation and operating the manipulator. It is mounted inside its own housing and has a tilt function. The camera's field of view is 97 degrees. High quality video is streamed directly to the surface via Ethernet with very little latency.

Figure 2.9: *Main camera housing, with IP-camera mounted together with a small servo for tilt control.*

Rear- and side-view camera

The rear-view camera is a Logitech USB webcam that has been stripped of its original housing and mounted inside an acrylic tube with aluminum end-caps. The camera connector runs into the Raspberry Pi inside the electronics housing. The last camera is a Raspberry Pi camera module mounted inside the electronics housing pointing outwards to one side to give a side-view. The video-feeds from these two cameras are streamed up to the surface system via the Ethernet connection.

2.9 Surface control system

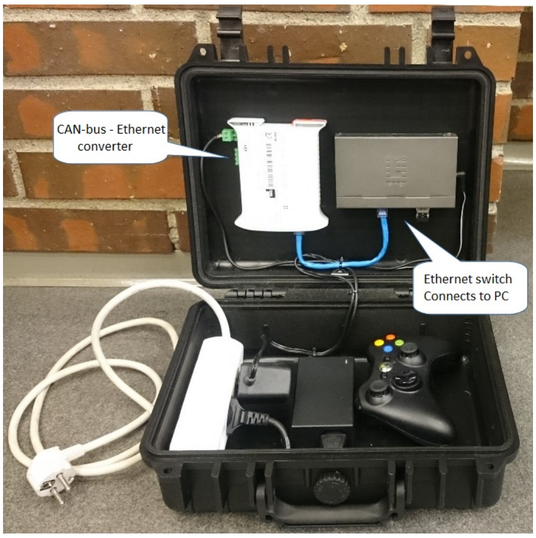

Figure 2.10: *Plastic case used at surface as interface between control system and Ægir.*

The surface system is based on a laptop with an external monitor connected. The external monitor is used to show the main camera video feed. The laptop monitor is used to show the graphical user interface and the rear- and side-view video feed. A plastic case containing a CAN/Ethernet-converter, Ethernet switch, power outlet and an Xbox-controller functions as the interface between the surface control system and *Ægir*.

The surface control system software is written in Python. "PyGame" third party library (among others) is used to read data from a Microsoft Xbox controller.

2.10 Communication

The communication, with the exception of the camera video-feed, has been realized by using the CAN-bus standard. CAN-bus is based on broadcasting messages which, among various other fields, include an identifier stating the message content. Subsystems on the network then use a programmable hardware filter to sort out the identifiers relevant to that specific subsystem. This type of communication makes it possible to easily connect and disconnect subsystems while the system is running. The flexibility of CAN-bus has proved to be very useful under the development of *Ægir*.

The controller output from the Xbox-controller at the surface is scaled and routed over Ethernet to the CAN-bus network. Similarly all sensor data sent up via CAN-bus is received by the CAN/Ethernet converter and transmitted over Ethernet to the surface system where the values are displayed for the operator.

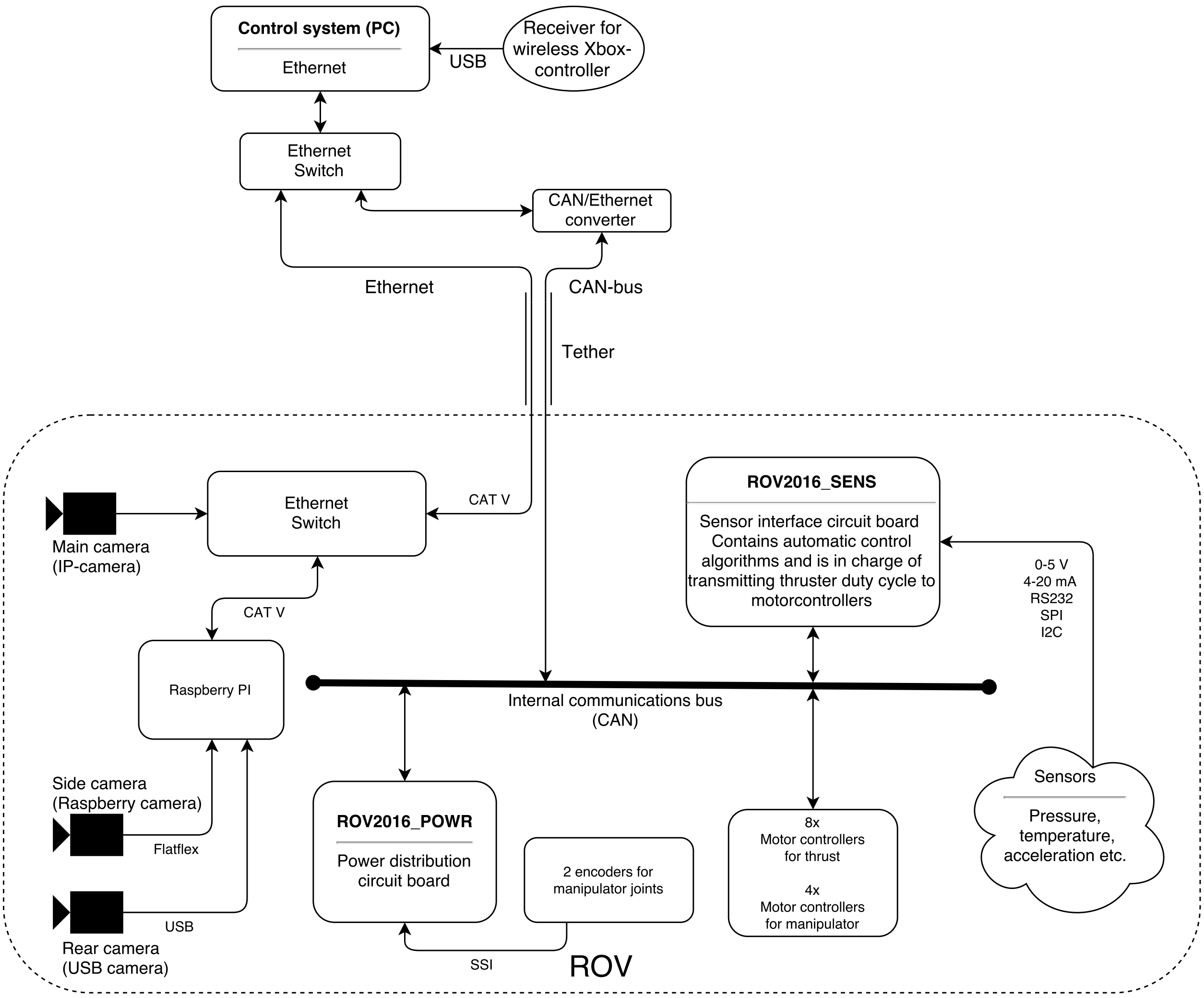

Figure 2.11: *Communications System Interconnect Diagram(SID).*

2.11 Sensors

Interface

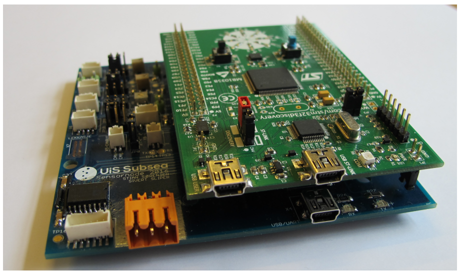

Figure 2.12: *Sensor interface board.*

A circuit board, based on a STM32F3DISCOVERY microcontroller development board, has been designed to realize an interface to the various sensors used on *Ægir*. The circuit board design is focused on flexibility and low susceptibility to electromagnetic interference(EMI). This is because all electronics are located in the same housing, and thus are prone to EMI caused by the nearby voltage converters and the rapidly changing thruster current consumption.

Depth measurement

In order to measure the thickness of ice sheets and ocean depth on Europa, a digital pressure sensor has been epoxy-cast into a stainless M12 bolt; leaving only the measuring membrane exposed. The bolt is then mounted in the stern end-cap. The pressure sensor has a tested accuracy of ±1 cm, and also contains a temperature sensor. The temperature sensor is used for compensation of measurement errors due to temperature change. Calibration of the sensor to atmospheric pressure can be done at any time from the surface control system, and is also performed upon system initialization. The pressure measurement is converted from a digital pressure value into depth in mm, and transmitted to the surface control system. The depth measurement is also used to enable automatic control of depth.

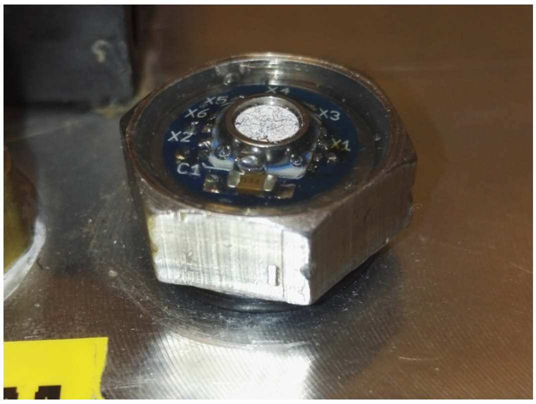

Figure 2.13: *Pressure sensor module mounted onto the stern end-cap.*

Temperature measurement

To measure temperatures of venting fluids on Europa's seafloor, an analog Centigrade temperature sensor accurate to within ±0.5 ℃ is used. The sensor is placed at the end of the manipulator, so that it may be inserted into a vent; and held stable there for the required 5 seconds [4].

Safety sensors

Internal temperature measurement and leakage detection has been implemented inside the electronics housing to increase the vessels safety under harsh conditions. The leakage detector is based on the fact that if a leakage occurs, water will create an electrical connection between two partially exposed wires placed strategically in the electronics housing. Internal temperature is monitored to ensure that the *Ægir*'s maximum recommended operating temperature of 60 ℃ is not exceeded. Internal temperature and leakage detection data is transmitted to the surface control system and presented in the graphical user interface. This ensures early warnings in case of water-leakage or overheating.

Attitude

To get an accurate estimate of attitude, i.e. the vessel's angular position, the company has developed a custom sensor fusion algorithm to combine both state variables and sensor measurements. The algorithm uses variable weights to produce an optimal combination of accelerometer and gyroscope state estimates; and thus reduces measurement noise without causing time delays. This, in turn, enables precise and stable automatic attitude control.

2.12 Automatic control system

To greatly reduce the workload of the operator while performing precision tasks, the company has developed algorithms for automatic control of depth and attitude(pitch and roll). The algorithms enable the vessel to maintain a set depth and pitch/roll angle. For example, the vessel can stay perfectly horizontal and at the right depth while inserting an ESP-connector to a power and communications hub. The automatic control algorithms can easily be switched on and off from the surface control station. During testing, the company found that *Ægir*'s power consumption is reduced by 88 % while hovering in automatic mode compared to manual hovering. In AUTO mode, the ROV will maintain its depth within 16 mm, and attitude within 2.6 degrees.

There are many other scenarios where the mission would benefit from the automatic control system. For example, because *Ægir* can hold its depth and attitude stable, positional drift is minimal. This, in turn, opens up opportunities to control *Ægir* via a wireless link between the surface and a remote control station. Such a wireless link would normally have too much time delay to effectively operate a ROV manually. With a wireless link and the automatic control systems, it would be possible to control *Ægir* from great distances. In case the remote control station looses communication with the ROV, *Ægir* would simply hold still until the communication link is re-established; avoiding potentially destructive contact with the surrounding environment.

2.13 Microcontroller firmware

In order to make firmware development structured and efficient, a module-based approach has been used. This approach has been implemented by separating the code into different modules depending on content; and by making sure that the modules are as independent as possible. This allows modification of firmware in a module with little to no alterations in other modules. With this approach, the company can efficiently make application-specific programs to better suit individual exploration tasks.

All firmware for microcontrollers in *Ægir* is written in the programming language C. The programs are scheduled by implementing periodic and non-periodic interrupts from peripheral modules in the microcontrollers. In this way, the microcontrollers will respond quickly to any events and received control signals.

3 Safety

3.1 Safety philosophy

UiS Subsea and the University of Stavanger operates with a zero tolerance approach regarding serious damage or illness associated with a project like this. Therefore, a safe work environment for our team members is important. Including the regulations from the University, UiS Subsea follows operational JSAs for both producing and operating *Ægir*.

3.2 Lab safety protocol

The University of Stavanger has set several rules when it comes to mechanical- and electrical machines. Both the Department of Mechanical Engineering and the Department of Electrical Engineering arranged lab safety courses in the 2015 fall semester. All members of the 2016 UiS Subsea ROV team have attended both courses, giving the team knowledge in safety lab protocols across the field of studies. This corresponds well with UiS Subsea's and the University's zero tolerance for serious damage and illness related to lab work.

When working at the University lab, safety goggles are required at all times. In noisy environments, ear protection is required. When doing tasks involving separation of dust and microparticles, proper ventilation and use of respiratory devices is mandatory.

3.3 Vehicle safety features

Mechanical

The tether has been equipped with a strain-relief made out of aramid to prevent any damages to the connectors if the tether is exposed to strain. The tether also has a sleeve to protect the cables from damages such as cuts. All sharp edges have been deburred to ensure safe handling and operation.

Electrical

All components using electrical power are protected with fuses, which are dimensioned according to operating currents. There is a button on the controller that shuts off the power to the motors manually. Also, if the communication is lost, all power to the motors will shut off.

3.4 Safety checklists

Pre-launch

1. Personal safety equipment ON
2. Ensure that all O-rings are in place, undamaged and properly greased
3. Ensure that no bulkhead connectors are loose
4. Check that all locking sleeves are tightened in place
5. Ensure that the blind plug is fastened finger tight
6. Check that the electronics housing is fastened
7. Check that all horizontal thrusters are properly fastened with clevis pins
8. Check that all propellers are fastened in place
9. Hands off ROV before turning power ON
10. Control voltage level and current limiting of power supply if applicable
11. Control status indicator LED's
12. Do not let the electronics house be closed with power ON above water for a long period of time due to heat accumulation inside the electronic housing

Launch

1. Keep hands away from thrusters
2. No hands on control system
3. A minimum of two people launching the ROV
4. Slowly launch Ægir
5. Keep Ægir calmly under water for 10s, check for bubbles
6. Pull Ægir up from water. Inspect waterproof housings for leakages
7. Tether assistance ready
8. Slowly launch Ægir

Post-launch

1. Power OFF and wait for 5 seconds
2. Pull Ægir up
3. Check for major damages
4. Rinse ROV with fresh water

4. Project Budget and Costing

Field	Item	Description	Type	Qty	Cost (NOK)	Total (NOK)
Mechanical	O-rings	Connectors and housings	Purchased	1	kr 1 000,00	kr 1 000,00
	Connectors	Subconn Connectors	Donated	24	kr 1 500,00	kr 36 000,00
	Bearings	Stainless SKF W-series bearings	Donated	31	kr 150,00	kr 4 650,00
	Picatinny rails		Purchased	4	kr 50,00	kr 200,00
	Gears	Delrin: Worm and spur	Purchased	10	kr 100,00	kr 1 000,00
	Timing pulley and belt	Syncroflex belt, aluminium pulley	Purchased	3	kr 75,00	kr 225,00
	Leadscrew	Tr8x1.5 Screw, Flanged nut	Purchased	2	kr 300,00	kr 600,00
	Linear rail	Low profile, lubrication free	Purchased	2	kr 210,00	kr 420,00
	Thruster duct	3D-printed	Donated	8	kr 250,00	kr 2 000,00
	Propellers	3D-printed	Purchased	8	kr 200,00	kr 1 600,00
	Supports	3D-printed	Donated	6	kr 80,00	kr 480,00
	Clear Epoxy	Loctite 3430	Purchased	1	kr 285,00	kr 285,00
	Thermal Conductive Epoxy	MG Chemicals 832TC	Purchased	1	kr 1 500,00	kr 1 500,00
	Fasteners	Stainless A4: Nuts, Bolts, Clevis pins	Purchased	1	kr 500,00	kr 500,00
	O-ring grease	Molykote 44 Medium	Purchased	1	kr 400,00	kr 400,00
	Strain relief	Aramid	Purchased	2	kr 200,00	kr 400,00
	Tether sleeving	PVC 30m	Purchased	1	kr 300,00	kr 300,00
Materials	Aluminum	6082-T6 Channel, Billet, Sheet	Purchased	1	kr 1 800,00	kr 1 800,00
	Acryl tube	Ø200, Ø120, Ø24	Purchased	3	kr 150,00	kr 450,00
Labour	Welding		Donated	1	kr 1 000,00	kr 1 000,00
	Water-jet cutting		Donated	1	kr 500,00	kr 500,00
Electronics	Custom PCB		Purchased	2	kr 400,00	kr 800,00
	DC/DC converters		Purchased	4	kr 700,00	kr 2 800,00
	STM32 microcontroller		Purchased	2	kr 80,00	kr 160,00
	LED Diodes		Purchased	2	kr 55,00	kr 110,00
	Tether cables		Purchased	25	kr 40,00	kr 1 000,00
	Raspberry Pi +PiCam		Purchased	1	kr 450,00	kr 450,00
	Electronic Speed Controllers		Purchased	12	kr 1 000,00	kr 12 000,00
	Misc. parts for custom PCB		Purchased	1	kr 2 500,00	kr 2 500,00
	Motors for thrusters		Purchased	8	kr 120,00	kr 960,00
	Motors for manipulator		Purchased	4	kr 360,00	kr 1 440,00
	Encoders for manipulator		Purchased	2	kr 430,00	kr 860,00
	Ethernet switch		Purchased	1	kr 920,00	kr 920,00
	Cables and cable assembly		Purchased	1	kr 500,00	kr 500,00
	Cooling fans		Purchased	2	kr 110,00	kr 220,00
Topside	Computer		Re-used	1	kr 4 000,00	kr 4 000,00
	Xbox Controller		Re-used	2	kr 350,00	kr 700,00
	Monitor		Re-used	1	kr 920,00	kr 920,00
	CAN-bus converter		Donated	1	kr 800,00	kr 800,00
	Ethernet switch		Re-used	1	kr 500,00	kr 500,00
	TCU-case		Re-used	1	kr 500,00	kr 500,00
Total	Vehicle expenses					kr 87 450,00
Total ROV	Vehicle expenses	USD (1 NOK = 0.12 USD)		0,12	kr 87 450,00	**$10 494,00**
Travel	Airplane tickets					kr 124 000,00
	Shipping ROV	Estimated				kr 3 000,00
	Lodging					kr 30 000,00
Total						kr 157 000,00
Total Travel		USD (1 NOK = 0.12 USD)		0,12	kr 157 000,00	**$18 840,00**
Total Cost						**$29 334,00**

Budget ROV 2016 (1 NOK = 0.12 USD)	$29 154,60
Budget ROV 2016 (NOK)	**kr 242 955,00**
Manipulator	
Description	**Estimated cost (NOK)**
Motors	kr 1 245,00
Gears	kr 1 200,00
ESC	kr 1 200,00
Housing	kr 500,00
Sum	**kr 4 145,00**
Electronics	
Description	**Estimated cost (NOK)**
Microcontrollers	kr 1 000,00
Sensors	kr 1 500,00
DC/DC main	kr 3 520,00
Power distrubution	kr 1 500,00
Camera	kr 3 000,00
PCB production	kr 5 000,00
Can-converter	kr 800,00
Sum	**kr 16 320,00**
Thrusters	
Description	**Estimated cost (NOK)**
ESC	kr 7 490,00
Motors	kr 4 150,00
Sum	**kr 11 640,00**
Travel	
Description	**Estimated cost (NOK)**
Flybilletter	kr 150 000,00
Hotell	kr 35 000,00
Frakt, ROV	kr 10 000,00
Sum	**kr 195 000,00**
Production	
Description	**Estimated cost (NOK)**
Coffee	kr 1 500,00
Frame-materials	kr 1 000,00
Electronics Housing	kr 1 250,00
O-rings	kr 900,00
Buoyancy	kr 2 500,00
Sum	**kr 7 150,00**
TCU	
Description	**Estimated cost (NOK)**
PC	kr 7 000,00
Tether	kr 1 000,00
TCU-case	kr 700,00
Sum	**kr 8 700,00**

5 Conclusion

5.1 Challenges

During the design phase, a challenge for the team was the allocation of space. The mechanical and electrical teams had to find a compromise on how big the electronics housing should be. The electrical team wanted as much space as possible, but the mechanical team wanted the opposite because of the size and weight restrictions [4]. This challenge was solved by having daily workshops and the use of the concept scoring matrix, in order to find the best solution that was good enough for both parties. Using this process, a variety of designs were discussed and evaluated.

The work towards a ROV with half the weight of previous ROVs has been a big challenge, it has forced the team to think in new ways and challenge established standards. The result is a small and lightweight ROV, with better maneuverability than what has been achieved earlier. The close cooperation, such as making 3D CAD models of all the electronics proved a valuable asset for the project as a whole and for the individuals which gained new knowledge and insight. One of two examples of major improvements are the LED headlights, which has gone from 50 cm^3 per unit to 1 cm^3 this year. Another improvement is the electronics housing, which has gone from 35 000 cm^3 to a much lower 6 900 cm^3.

5.2 Lessons learned and skills gained

Technical

There is no doubt that the team have gained knowledge on how to fit the electronics inside such a small housing. With hard work and dedication, the team came up with a good solution. This is a solution this year's team can be proud of and something future UiS Subsea projects can improve in the coming years.

Figure 5.1: *Part of the ROV team after a successful test with Ægir in the swimming pool.*

Interpersonal

The interdisciplinary collaboration between mechanical, electrical and computer engineers have given the team valuable knowledge when it comes to work in a real-world engineering team. Without involvement in a student organization like UiS Subsea, this is an experience we would not gain during our studies at the University.

5.3 Future improvements

Transfer of knowledge

In the two previous UiS Subsea ROV projects, there has been little transfer of knowledge. This has been a challenge due to the extensive change of team members in every ROV project. This has again been reflected in the results in previous MATE ROV Competitions. UiS Subsea has noticed that this needs improvement to achieve success in future MATE ROV Competitions.

Lean management

This year, the project managers have introduced "Lean Management" and a tool called "Value Stream Mapping" into the project. This tool have been used to map the project to easily spot any problems and wastes that have occurred. There has been suggested a solution to every problem and a guideline on how to remove the wastes. This has resulted in a suggestion of an ideal UiS Subsea ROV process. This ideal process is meant to be used as a guideline and should be further improved by future UiS Subsea ROV projects.

Experience report

To improve the knowledge flow, every team member of the 2016 ROV team will write an experience report. This will be studied by the member with the same area of responsibility in the 2017 UiS Subsea ROV project. UiS Subsea will also arrange a debrief between the projects, and start up meetings/workshops in the start of next year's project.

5.4 Reflection

This project has given its team members vital insight in the subsea industry and how it is to work as a subsea engineer. Hopefully, this will encourage them to work in the subsea industry after their studies. Through hard work and dedication over the last five months, we are confident in a good performance in the International MATE ROV Competition in Houston.

"Working with this project has been a remarkable experience. The last five months has been the toughest period during my time at the University of Stavanger, but by far the most memorable. I have have connected with electrical and computer engineers, something that I would not have done without involvement in UiS Subsea. I can't wait for the competition in Houston to start!"
Martin Evensen, Project Manager UiS Subsea ROV 2016

References

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[4] MATE ROV. *Mate rov competition manual EXPLORER*, 12 2015.

[5] Murata Power Solutions. *UWE Series*, 2012.