MATE

AARHUS UNIVERSITY

The Little Mermaid

St. John's, Canada 2015

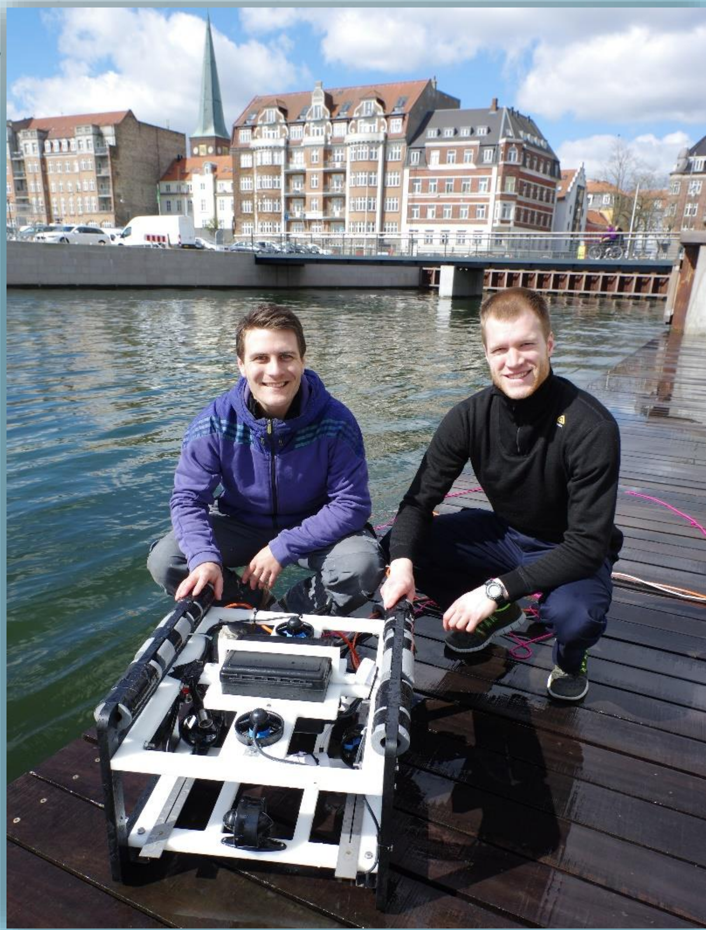
Aarhus University - Denmark

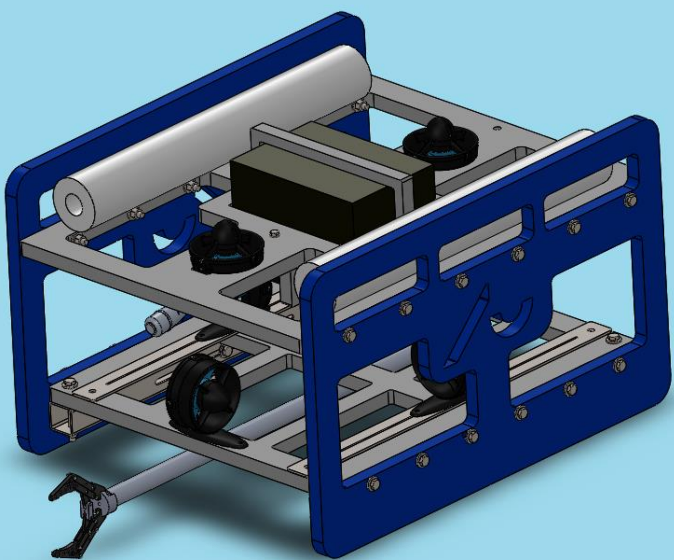
Instructor: Claus Melvad

Members: Poul Brix Christensen
CEO and co-pilot

Dennik Dan Ringgaard
CEO and pilot

Jens Brix Christensen
Engineer





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1 Abstract

This report describes the construction of the ROV(Remote Operated Vehicle), The Little Mermaid. The ROV is built for an underwater ROV competition held in Canada. Many aspects of the nature have influence on the final design. For example the pressure rises the deeper the ROV goes and this report describes how to overcome such obstacles in the design. The purpose of an underwater ROV is to complete tasks underwater. No matter the purposes, most factors are the same. Maneuverability, vision and stability are all key factors for the design. This paper accounts for how both the mechanical, electric and software aspects have to interact, as well as how people need to work together as a team. The project will end up having a fully functional ROV, by making strategic design choices with an engineering approach.

2 Presentation

This report is an outcome of a four-month study with focus on competing in the annual MATE ROV competition. The project is related to a bachelor project at Aarhus University, Denmark, with focus on building a ROV. This report introduces some of the key factors and components that are used when constructing such a vehicle. The project team consist of three mechanical engineer students, all from the Aarhus University School of Engineering.

2.1 Introduction

Humans are created to live on land, for this reason we have lungs to breathe. We can for a short while, exist under water, but the competences we have on land is not the same when in water. The water is in fact not where we belong. Therefore, it is much easier for us to investigate and operate on land. With more than 70% of the Earth’s surface covered with water, there is a lot of nature that are still unknown to us. Well, it has not stopped us from trying to investigate some places where we have difficulties to survive. We simply adapt to the environment by making suits. We can walk on the moon with a space suit and we can swim under water with a diving equipment. However, there is limits for humans even in a suit. A solution is therefore to send a robot. We can send a space car to the moon and it can stay there for years, and we can build a ROV that can go to cold water at the North Pole and stay there for hours. There are many things we still do not know about the nature, therefore it is interesting to investigate.

2.2 Specs and Scope

The specifications for the project is set by MATE(Marine Advanced Technology Education Center). There are several requirements, which all can be read in the Ranger manual, if more information is sought.

Listed below is some of the specifications this project must fulfil regarding the design:

- Max depth: 10m
- Temperature: -2/40˚C
- Max pressure: 2bar
- Max gripper weight: 20N

The project was started on 1st of February 2015 and has the first deadline in beginning of May. This means there is a tight timeframe for the project. Therefore, the project is managed with project tools in order to meet the deadline. This also mean that components and systems that are already waterproof, is preferred.

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Main Design

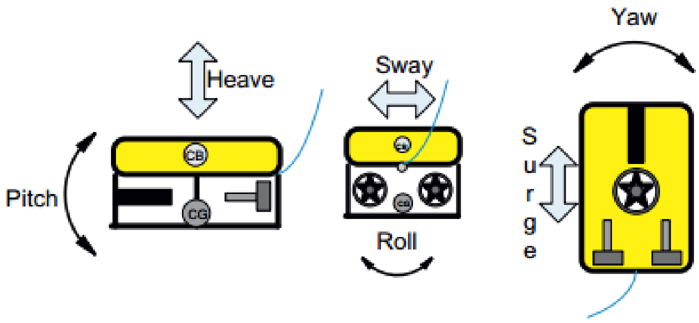
Before the actual design is developed, basic concepts needs to be clarified. This chapter describes which type of ROV we intend to build. Because there is many different ways to build a ROV for example the chassis can be square, triangular and spherical. A main key factor is maneuverability and therefore this has a big influence on the design of the ROV.

The ROV should consist of:

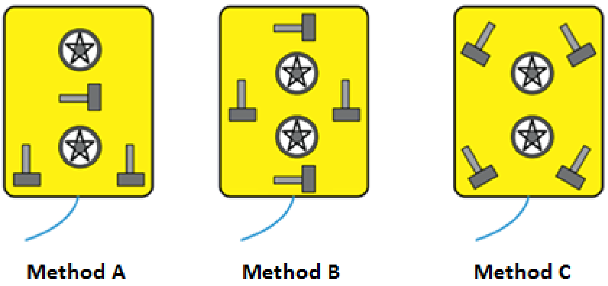
- Chassis made of plastic plates
- Thrusters x6
- At least one gripper
- At least one camera
- Controller
- Electric case
- Tether
- Float
- Screen
- Computer

The chassis is made out of plates because it is because then it is easier to attach components to the chassis. In addition, with the plates made of plastic the weight will be reduced compared to one made of metal metal. Due to the transportation to Canada, it is also easy to separate the ROV and assemble it again.

It is decided to have six thrusters in total due to the complexity of the tasks. It is necessary for the ROV to have at least five degrees of freedom to maneuver freely. In the picture xx, the different DoF(Degrees of Freedom) is shown, and based on this it is considered that the ROV does not need to 'Roll', but the rest is needed. This will result in five DoF in total.



The maximum allowance in the budget is six thrusters. There are different methods to place the thrusters in order to get the five DoF and three of them have been evaluated. The different method is shown at the picture below. It has been decided to have six thrusters in total due to the total power. Both method B and C have six thrusters but due to the current limit set by MATE, the method B is a better choice because in method C the power of the thrusters will not be fully utilized.



In order to work with the ROV both a camera and gripper is needed. The camera should be analog so there will not be any time delay on the screen. It is experienced that with a HD cam there will be delay, which will affect the handling and make it difficult for the pilot.

All the electronics are placed on the ROV so the tether will consist of fewer wires. With the myRIO placed onboard he ROV, the accelerometer inside the myRIO can be utilized.

To house all the electrics onboard an electronic box is needed. It needs to withstand the pressure and be waterproof. The electronic box is connected to land via a tether. This tether will consist of a power cable, communication cable and a video cable. The power needs to have the correct dimensions to carry the current flowing.

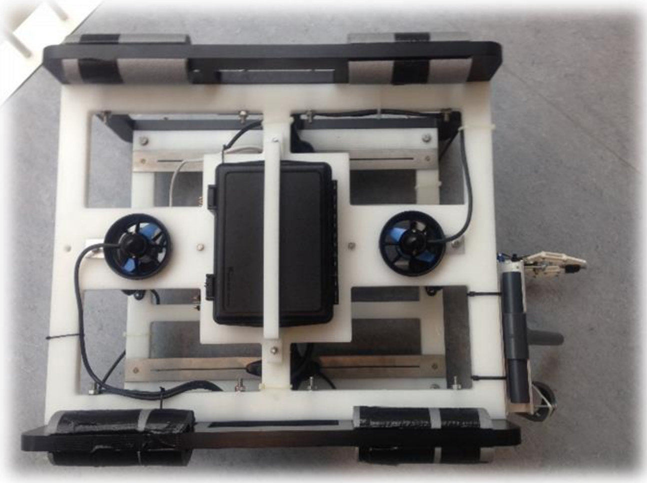
To control the whole ROV an embedded system is needed. Because the school is already using National Instruments and labVIEW, other potential options has not been studied.

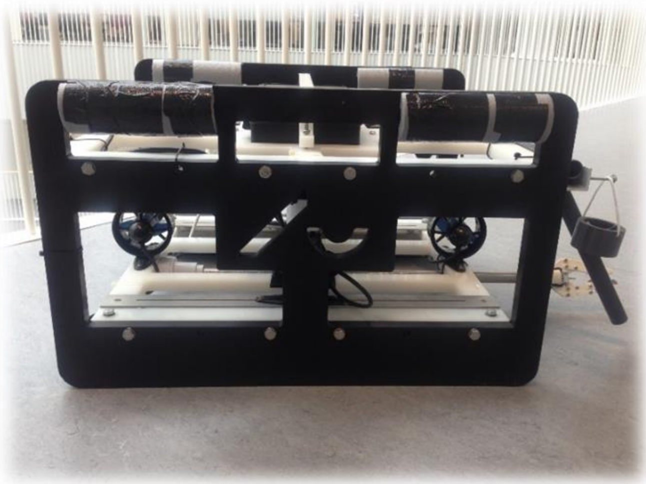
To control the amount of money that can be used to each part, a budget is created where the granted money is allocated to each component.

ROV BUDGET					
Granted Money	**3000,0 $**				
Money Spend	**2735,0 $**				
Money Left	**265,0 $**				
Buffer	**8,8 %**			Valuta	6,5
Description	**Qty**	**Allocated**			
Registration MATE	1	650	DKK	100	USD
Thrusters with ESC	6	4940	DKK	760	USD
Camera	1	2080	DKK	320	USD
Gripper	1	1495	DKK	230	USD
Screen	1	975	DKK	150	USD
Tether - Power	1	455	DKK	70	USD
Banana plugs	1	33	DKK	5	USD
Controller	1	293	DKK	45	USD
National Instruments myRIO	1	0	DKK	0	USD
Waterleakage sensor	3	98	DKK	15	USD
Pressure sensor	1	488	DKK	75	USD
USB/Ethernet converter	1	293	DKK	45	USD
Floats	2	488	DKK	75	USD
Props	1	975	DKK	150	USD
Chassis	1	2470	DKK	380	USD
Connectors	1	780	DKK	120	USD
Light		293	DKK	45	USD
Elec. Box	1	975	DKK	150	USD
	Total	**17778**	**DKK**	**2735**	**USD**

3 ROV design

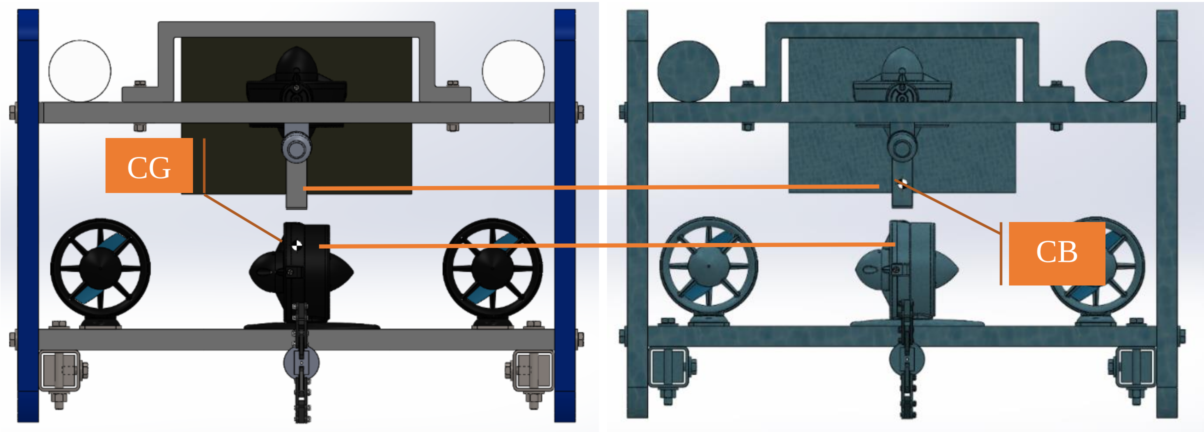
This chapter describes the design made on the ROV but also the selection of the components. There have been many ideas for the design and it have been through many iterations.





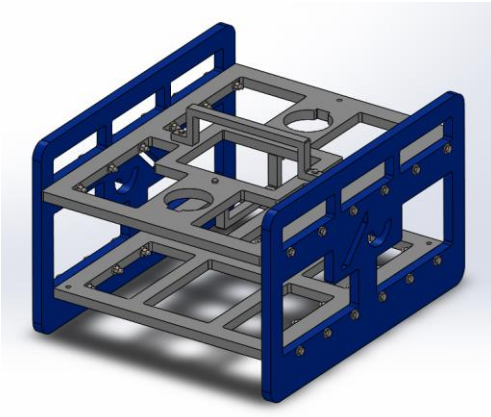
3.1 General

The design is made of four plastic plates held together with M8 bolts. All the buoyancy material is placed on top of the construction and some weight material at the bottom, in order to get a better stability. For the simplicity of the design, the chassis is symmetric. This makes it easier to place the center of gravity in the middle of the thrusters. In the process of the designing phase the center of buoyancy (CB) and the center of gravity (CG) have been checked at all times, to make sure the placing of all the components is in harmony. This is done with SolidWorks, a CAD program. The center of gravity can be calculated automatically with SW, if all parts and components have the right mass and geometry. The same goes for the CB, but here the whole construction is turned into water. Due to Archimedes law, the center of buoyancy must be in the center of the water displaced by the ROV. The distance between the two points is 58mm.



3.2 Chassis

The chassis is made of HDPE, High-density polyethylene. The reason for choosing HDPE is that the density is below the density of water, and therefore it will float slightly. Furthermore, the material can withstand temperatures below 0˚C. Another possibility is PP since it has a stronger E-module than HDPE but this material cannot resist minus degrees. Another crucial aspect when deciding what materials to use for underwater robots is the materials ability not to absorb water. This will result in a change of the constructions dimensions, which can have crucial consequences. In the case, HDPE is ideal and almost complete resistant. The construction is designed so the water flow from the thrusters do not interfere with each other.



3.3 Thruster

BlueRobotics thrusters will be used as propulsion for the ROV. Due to the budget allocated, this is the best solution on the marked. The alternative is to create one ourselves, but it will never get as good thrust as the BlueRobotics with the timeframe for the project considered. They each have a maximum current use of 12.5A, which means that two of the thrusters takes up the amount of current that is disposal. Therefor the current needs to be monitored, so the 25A fuse will not break.

3.4 Case

The electronic box is a flightcase. The advantage of this is that it is already tested to a depth of 10m, which is a requirement. Furthermore, it has a thick wall that will give a good stability so the walls will not buckle. The downside with this is the drag coefficient due to the square design. In addition, it could be a concern that the square shape cannot resist the pressure, but at 10m, there is approx. 2bar, which is not being considered as crucial to the design.

3.5 Connectors

The tether is connected with the electronic box with some plugs. This is in order to disassemble them from each other so it is easier to move the two parts. The motor cables is not made with plugs because it takes a lot of space and makes the electric case weaker due to all the holes. Therefore, the amount of holes are reduced by having more cables through one hole.

3.6 myRIO

Parts and software from National Instruments is used to control the ROV. A myRIO is used as hardware and labVIEW is used for the software. With these parts, it is simple to create some advanced programming with a mechanical background. Besides the easy programming, there is several advantages with the myRIO such as light product, quick dual core processor, integrated accelerometer and fully configurable FPGA.

3.7 Controller

An Xbox-controller is used for steering the ROV. This control unit is easy compatible with the myRIO and can therefore easily be included in the programming. The advantages is that many control functions is in close hand and it is an already known control type. Furthermore, we had some test persons to help us defining the most intuitive controlling. This have led to a very simple controlling of the ROV, which makes good sense for the human brain.

3.8 Gripper

There was no gripper found that fulfilled the requirement. The gripper is therefore a 3D printed prototype. The gripper will be developed after some testing with the prototype in order to get some experience. The actuator for the gripper is a modified bilge pump. The propeller is dismounted so the rotor can be connected together with the gripper. The advantage with a bilge pump is that it is already waterproof.

3.9 Float

Both the float for the ROV and the tether is made of a foam that are normally used for isolating pipes. The foam material has a very low density (30-40kg/m^3) and has a good immunity to absorbing water. This makes it perfect for floating material. The amount of material depends on density of the ROV without the buoyancy material. To get the most stable and efficient ROV, the total density should be just below 1kg/m^3. Because not all components are included in the CAD model, the construction will be heavier than calculated. Therefore, it will be constructed as extra buoyant by making a safety margin.

desired density of ROV: $den_{ROV} := 1\frac{gm}{cm^3}\cdot(100\% - 10\%) = 0.9\cdot\frac{gm}{cm^3}$

The ROV w/o float:

Mass of ROV w/o float: $mass_o := 20663.55gm$

Volume of ROV w/o float: $vol_o := 19644cm^3$

Density of ROV w/o float: $density_o := \frac{mass_o}{vol_o} = 1.052\cdot\frac{gm}{cm^3}$

Calculation of the lenght of float:

Outer diameter of float: $dia := 72mm$

Thickness of float: $tyk := 22mm$

Float density: $density_f := 35\frac{kg}{m^3}$

Cross-section float: $A_f := \frac{\pi}{4}\cdot\left[dia^2 - (dia - 2\cdot tyk)^2\right] = 3.456\times 10^3\cdot mm^2$

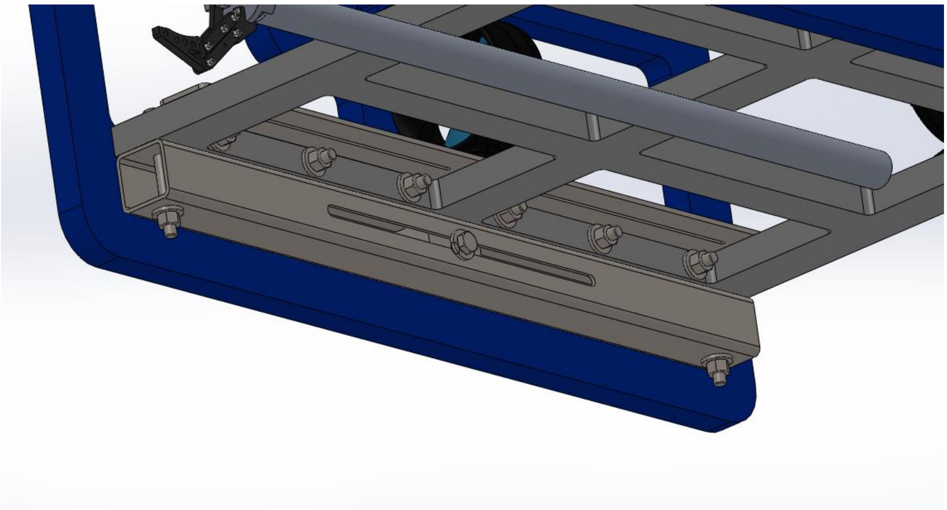
Length of float to make the total ROV density 0,90:

$$S_{float} := \frac{\left[mass_o + \left(A_f\cdot S\cdot density_f\right)\right]}{\left[vol_o + \left(A_f\cdot S\right)\right]} = den_{ROV} \;\begin{vmatrix} solve, S \\ float, 2 \\ simplify \end{vmatrix} \rightarrow \frac{6934.0\cdot gm\cdot m}{kg} - \frac{5.9e6\cdot cm^3}{m^2}$$

Lenght of float on both side: $\frac{\left|S_{float}\right|}{2} = 517\cdot mm$

3.10 Weight adjustment

In order to adjust the weight point after the ROV have been launched, some weight blocks has been added at the bottom of the ROV. These can slide forward and backwards to adjust the static pitch angle.



3.11 Tether

The tether consist of three cables.

- Power Cable
- Communication Cable
- Video Cable

The power cable will supply the ROV with 12V from land. What is crucial here is the power loss in the cable, which can have big influence on the performance. It is therefore a balance between a big power cable and a big voltage drop. With a voltage drop too big, the ROV cannot dive. With a power cable too big, the ROV will not be able to drag the cable. The calculation of minimum cross section of the wire is then:

$q := 0.0175 \frac{\Omega \cdot mm^2}{m}$ Specific resistance for cobber

$L := 2 \cdot 18m$ Length of tether

$I := 25A$ Curren

$$kvd := \begin{pmatrix} 2 \cdot 2.5 \\ 2 \cdot 4 \\ 4 \cdot 2.5 \\ 4 \cdot 4 \end{pmatrix} mm^2$$ Possible cable sizes

$$\frac{q \cdot L \cdot I \cdot 2}{kvd} = \begin{pmatrix} 6.3 \\ 3.938 \\ 3.15 \\ 1.969 \end{pmatrix} V$$ Voltagedrop acording to cable size

The $4x4mm^2$ seems as the best solution, but the cable might be too heavy, so the $4x2.5mm^2$ is chosen instead. The cable will be a H07-rubber cable, which is very flexible. This makes the ROV very maneuverable. Due to a smaller cross-section.

The communication cable is a cat6-ethernet cable. This cable has twisted wire so the interference from the power cable is minimized.

The video cable is a pre-attached cable that is already mounted on the camera.

3.12 Tilt

Because there is no automate adjusting of the CG after the grippe has grabbed something, it needs to be insured that the ROV can still lift.

Calculate the moment around CB:

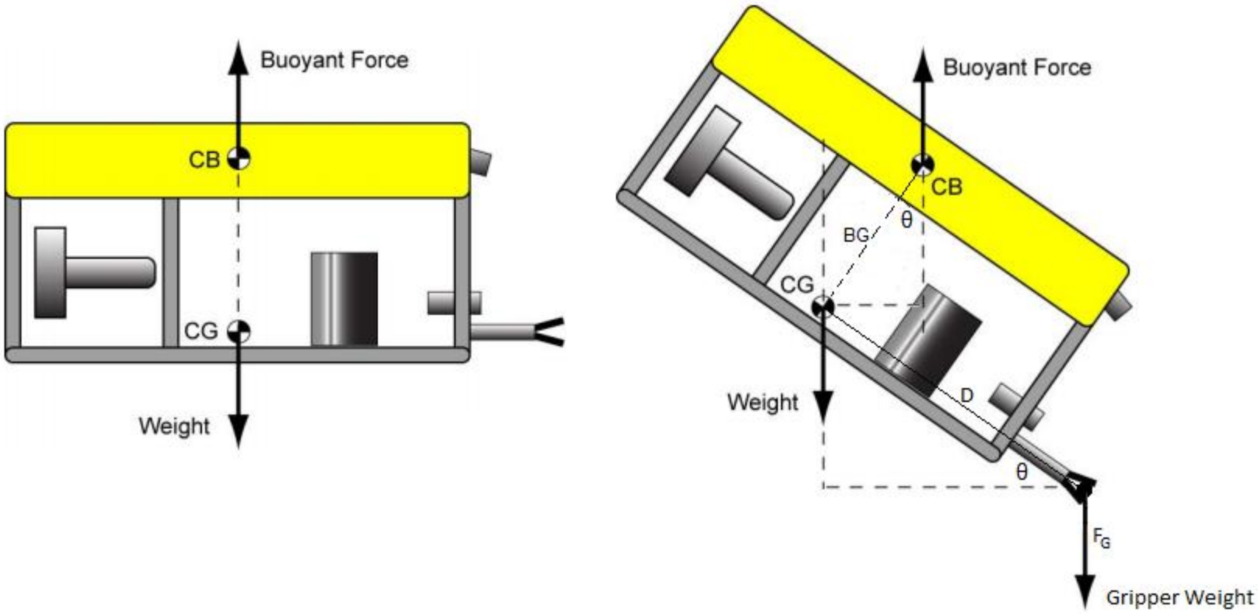
$$\sum M_{CB} = CG * \sin(\theta) * BG - F_G * \cos(\theta) * D = 0 \rightarrow$$

$$CG * \sin(\theta) * BG = F_G * \cos(\theta) * D \rightarrow$$

$$\frac{\sin(\theta)}{\cos(\theta)} = \frac{F_G * D}{CG * BG} \rightarrow$$

$$\tan(\theta) = \frac{F_G * D}{CG * BG} \rightarrow$$

$$\theta = \arctan\left(\frac{F_G * D}{CG * BG}\right)$$

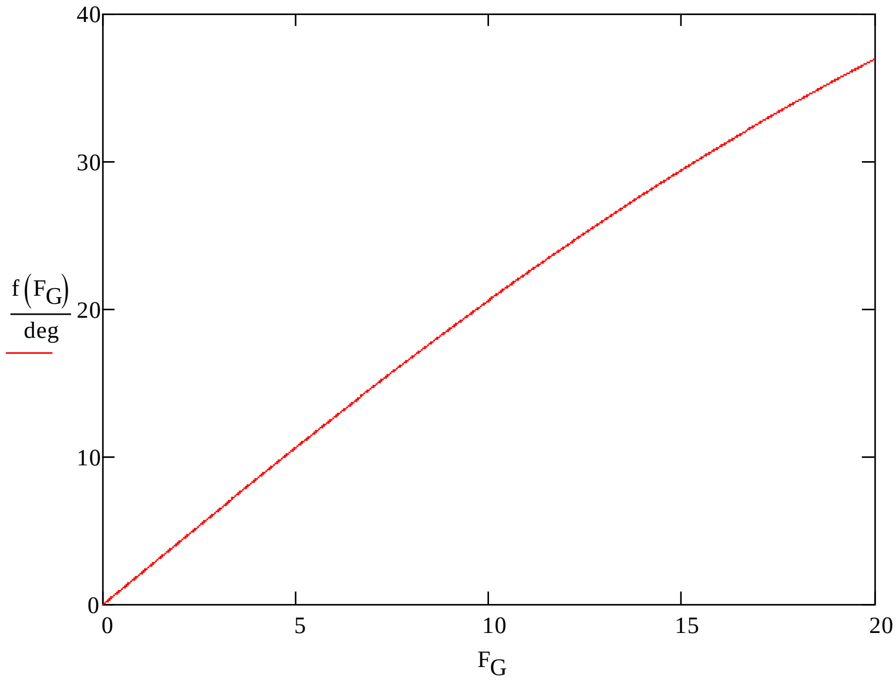


Data is obtained from SolidWorks:

$m_{rov} := 21kg$ $D := 450mm$ $BG := 58mm$

By expressing the angle as a function of force acting on the gripper:

$$f(F_G) := \text{atan}\left(\frac{F_G \cdot D}{m_{rov} \cdot g \cdot BG}\right)$$



The maximum angle for the ROV with the maximum force of 20N acting on the gripper:

$$f(20N) = 37 \cdot deg$$

When the thrusters are angled, it is not 100% power that is used for lifting, but only component of the max thrust. Therefore, it needs to be checked whether the ROV has enough thrust for lifting.

It is assumed that the density of the ROV is 1kg/m^3 and can therefore be neglected. Therefore, the thrusters only need to overcome the force acting on the gripper, which is the 20N. The thruster have a strong side and a weak side, meaning it is not producing the same amount of thrust both forward and backwards.

$$F_{good} = 2 * 23N * \cos(\deg 37) = 36.7N$$

$$36.7N > 20N \rightarrow ok$$

$$F_{bad} = 2 * 18N * \cos(\deg 37) = 28.8N$$

$$28.8N > 20N \rightarrow ok$$

The ROV can lift the object both with the strong and weak side of the thrusters.

4 CFD

With the ROV fully submerged in water, it would be logical to look at the flow around the structure. During the design face, the ROV had been designed with many openings in the structure to let water flow freely. Especially forward, a low drag coefficient was wanted. To check whether this was complied, a flow analysis was set up. For that, a speed was need. From earlier tests in pools, we had estimated the top speed of the ROV to about 0.8m/s. This speed was used in the analysis.

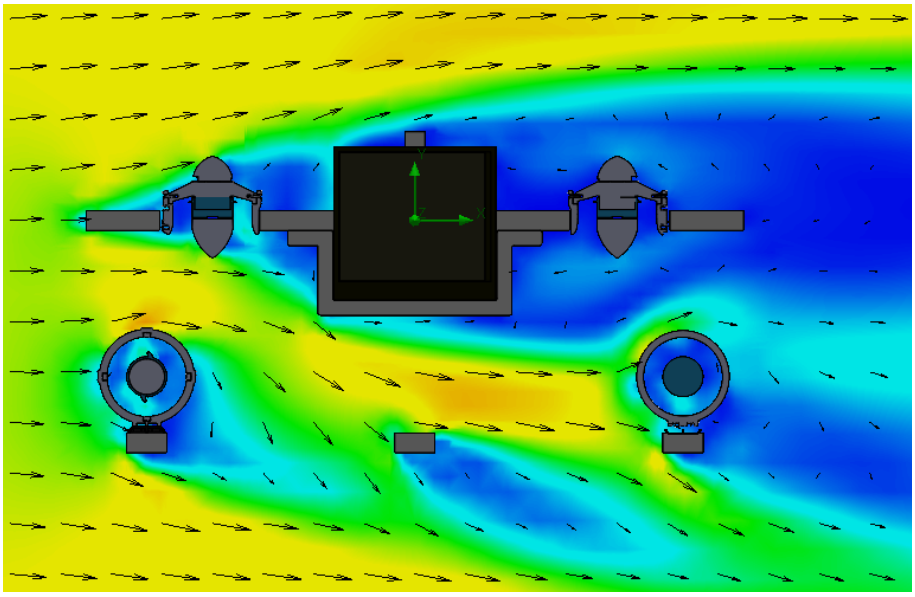
Usually in such work, the drag coefficient is the wanted result, but this number can only be used if you have something to compare it with. For example in the car industry, this makes sense. It is easy to compare two cars side by side, based on the drag coefficient. However, it does not make sense to compare a ROV to a car.

Instead, we looked at force needed to reach 0.8m/s in three directions. Forward, sideways and downwards. This is the results:

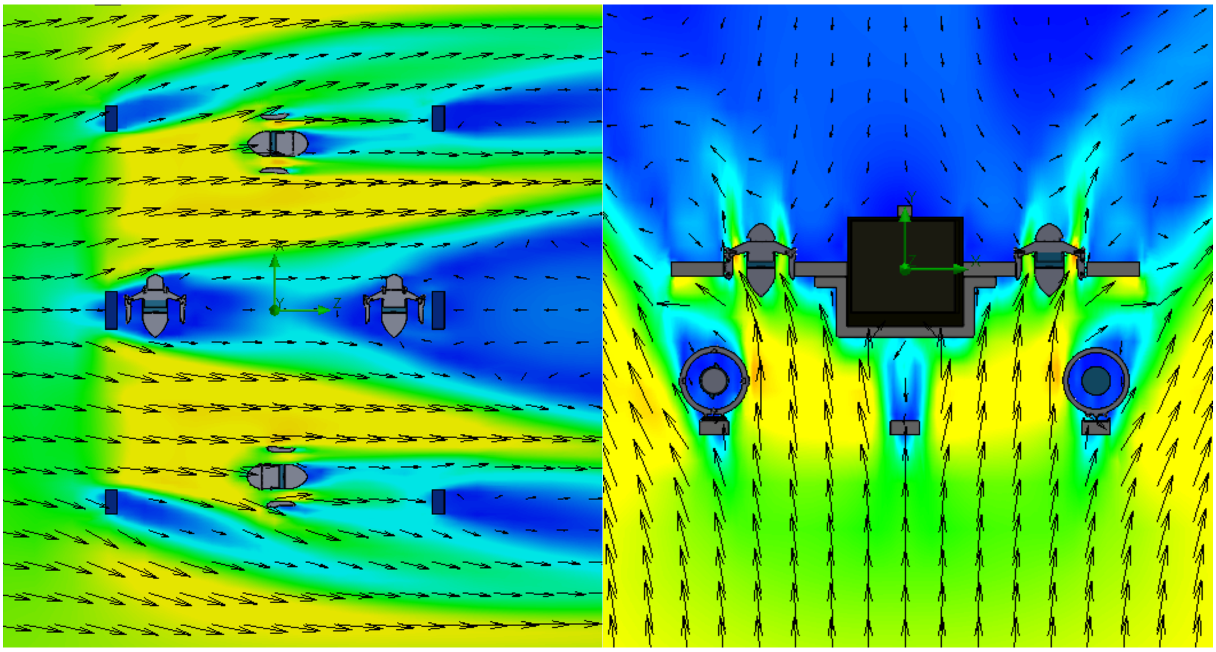
	Forward	Sideways	Downward
Speed	0.8m/s	0.8m/s	0.8m/s
F_D	39N	76.N	96N

Forward 39N of thrust is required to reach 0.8m/s. The two thruster are capable of delivering 46N of thrust, which make our estimated top speed plausible. Sideways the needed thrust is close to the double. Downwards we see the worst results. This is easier to understand by looking at the visualization of the drag. The blue zones is the result of higher drag.

This is a section view to show the drag of the forward motion.



Here are the section views for sideways and downward motion.



What can be interpreted from this? The ROV has the least amount of drag in the forward motion, just as it was wanted. The sideway and down drags are much bigger, but the sideways drag does not make that a big deal. Since sideways motion are most of the time used for small precise maneuvers, so speed is not a key factor. However, the ROV could gain from minimizing the drag for the up and down motion. Another important interpretation is that the electric box is creating most of the drag. Just by rethinking this box, the drag will be rectified a lot.

5 Electric

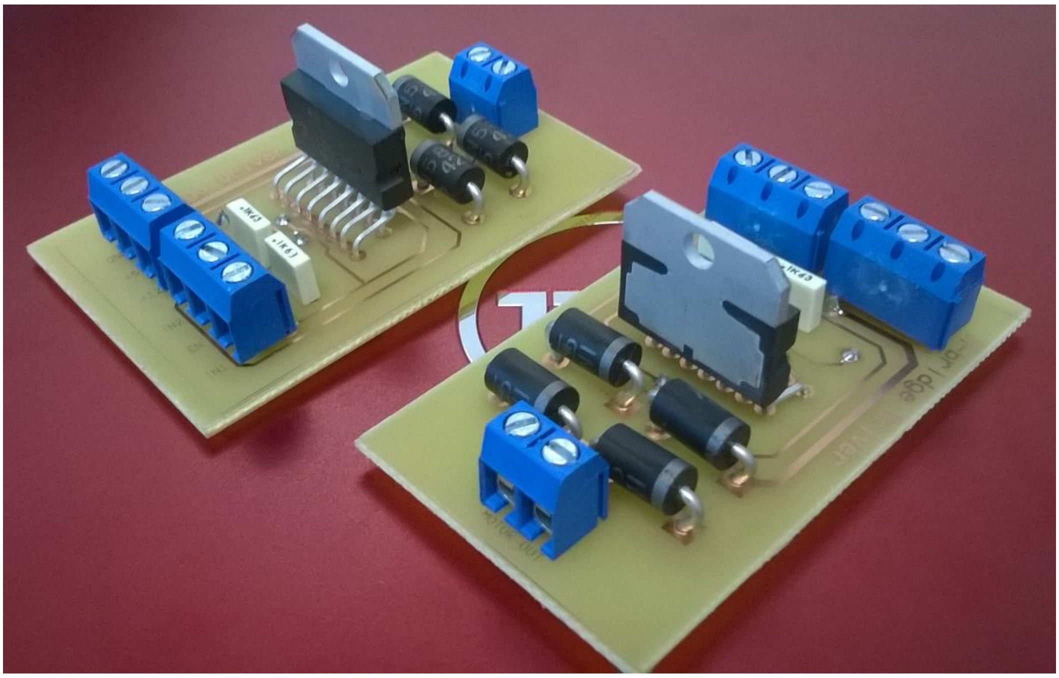
The surface system consist of a computer, video monitors and an Xbox 360 controller. The onboard analog cameras on the ROV is hooked up directly to the video monitors. The Xbox 360 controller is connected to the computer by USB.

The tether consist of different types of cable, a power cable, analog video cable and an Ethernet cable. Normally a myRIO is connected to a computer with a USB cable or through Wi-Fi. Since USB cables are limited by their length and wireless connections does not work underwater, another solution had to be found. The myRIO runs a Linux based OS that supports ASIX chipsets. This means an USB/Ethernet adapter based on that chipset would work. Now it is possible to use Ethernet as data exchange between the myRIO and the surface computer.

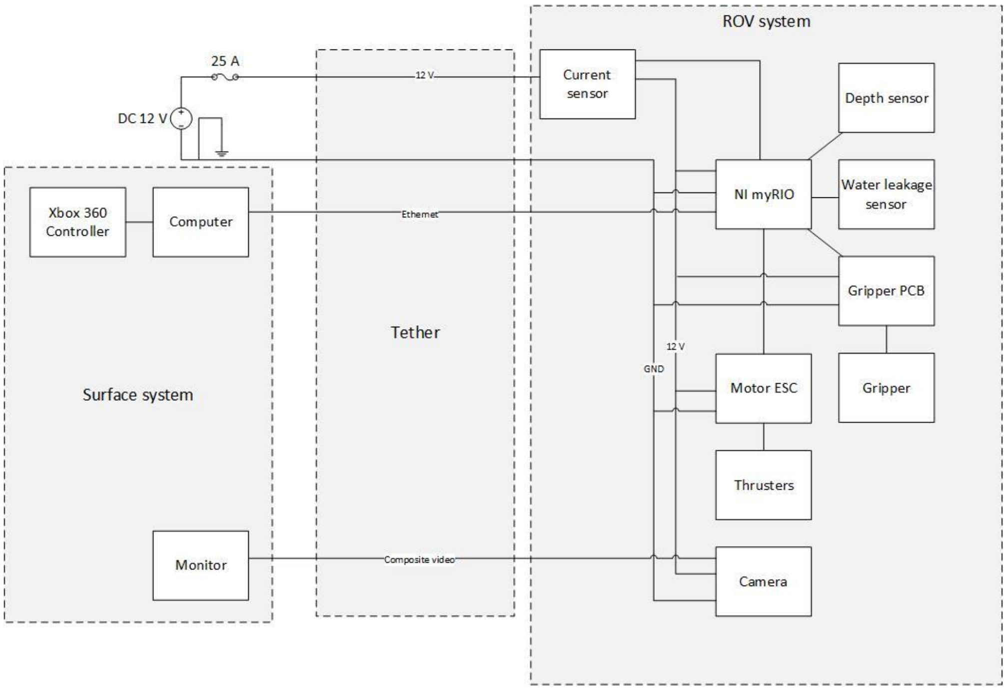
The ROV system is based on the myRIO. It is an embedded system with 10 analog inputs, 6 analog outputs, 40 digital I/O lines and a built-in accelerometer. All sensors, current-, depth- and water leakage sensor are connected to the myRIO, it then processes the signal and sends it to the surface computer.

The thrusters are controlled by a standard ESC(Electronic Speed Control), which only need a PWM(Pulse-Width modulation) signal from the myRIO. This mixed with the Xbox 360 controller gives fully step less control over the thrusters.

The actuator on the gripper, is a stripped down bilge pump, which is a DC motor. To control this an H-bridge is designed and built.



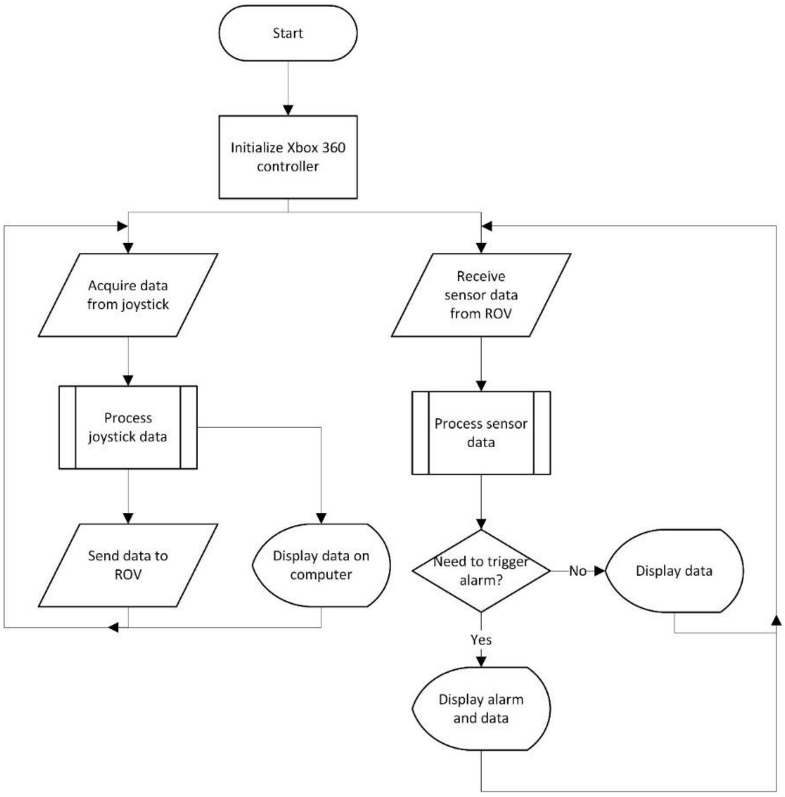
The current sensor is used to keep the ROV's current consumption under 25A. Since it is capable of using above 25A, the sensor is used as feedback in the software to adjust the PWM signal. This way the current consumption is limited.



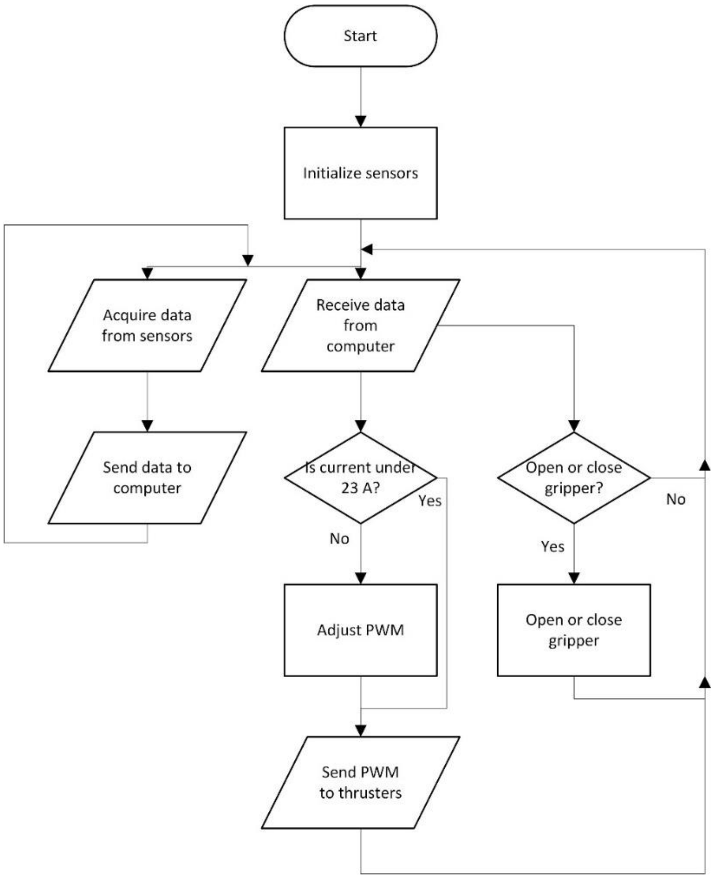
6 Software

The software is running on both the myRIO and the computer. Nearly all the processing is done on the computer to spare the processor on the myRIO, since the computer is much faster. After the program has been started, it initialize the Xbox 360 controller, the sensor and the IO.

On the computer, the steering algorithms is applied on the input data from the Xbox 360 controller. The data is then send to the ROV. The same data is also displayed on the GUI(Graphic User Interface), to help maneuver the ROV. At the same time, the computer is also receiving the sensor data from the ROV. The computer process the data, and display the necessary data on the GUI.



Onboard the ROV, the myRIO receives data from the computer. This data is used to control the thrusters and grippers by PWM signals. If the current consumption gets near the limit of 25A, the PWM is adjusted to make sure the current consumption stays below 25A. The myRIO is also passing on data from the sensor to the computer.



7 Project management

From the start of the project, we made a time schedule to keep track of tasks and time. The time schedule was updated at least once every week to maintain its effect. This way it was used to keep focus on a single task, even if the project seemed big and unmanageable. It can also be used to see the bigger picture. Are we behind or ahead of schedule, and what are the upcoming deadlines and tasks? With these two properties, the time schedule helps maintaining a good workflow throughout the whole project.

On a daily basis, project management is executed more like scrum. There will be held a 15-minute meeting every morning. At this meeting, every team member goes through three highlights:

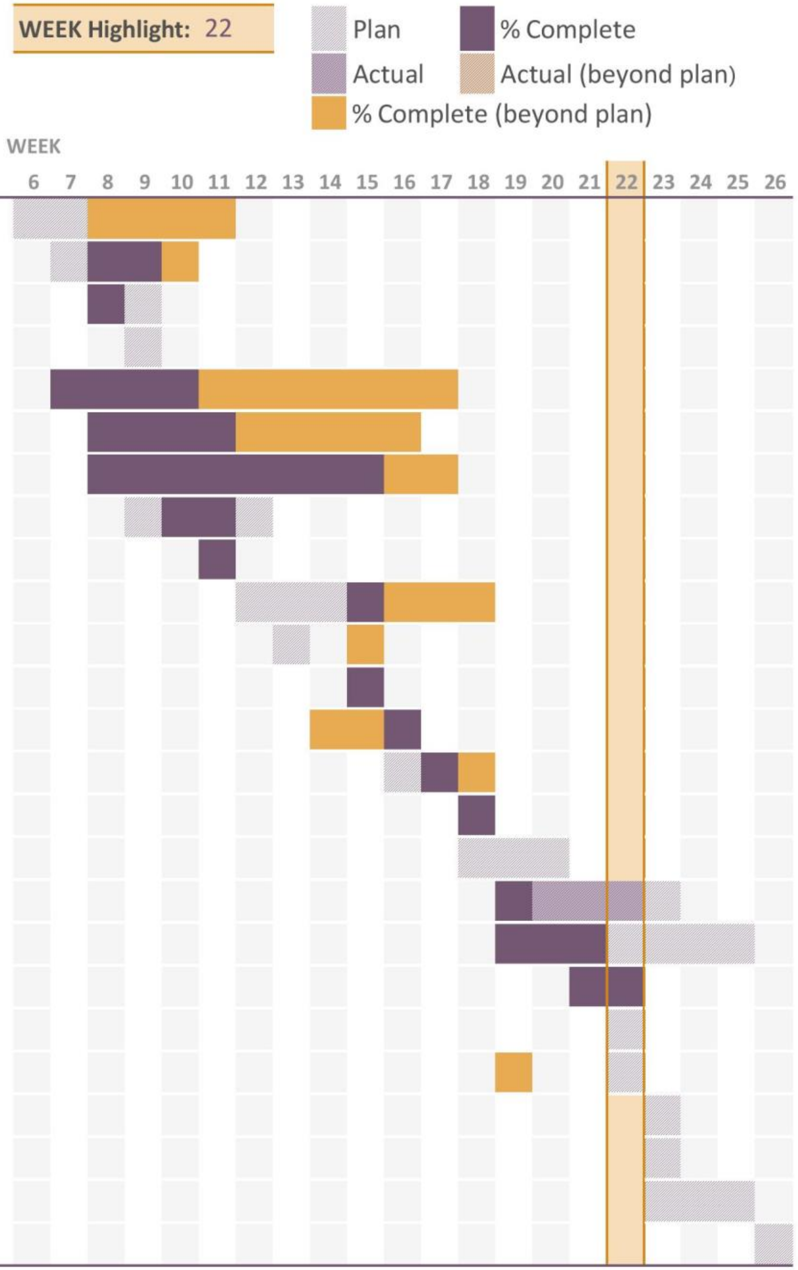
- What did I do since yesterday to help achieve the team's goal(s)?
- What are the goal(s) for today, and how can I help achieve them?
- Do I see any problems in relation to the goal(s)?

Since it is on daily basis, these goals are small, and smaller goals are easier to cope with, which helps keeping focus. It also makes sure that everybody knows what the others are doing, so two people do not end up solving the same task. A team member might have a solution to what another might perceive as a problem.

On every subtask, responsibility was assigned to a person. This does not mean the person has to complete the task himself, but he has the responsibility for the task being done in time.

Underwater ROV

ACTIVITY	PLAN START	PLAN DURATION	ACTUAL START	ACTUAL DURATION	PERCENT COMPLETE
Handin bachelor project specification 02.15 2015 12::	6	2	8	4	100%
MATE competition sign up 03.01 2015	7	3	8	3	100%
Fluid power quiz 03.01 2015	8	2	8	1	100%
Handin laser specification to MATE	9	1			0%
Component choice	7	4	7	11	100%
CAD drawings	8	4	8	9	100%
Software	8	8	8	10	100%
Build props	9	4	10	2	100%
Trip to Copenhagen, visit at Peter Madsen	11	1	11	1	100%
Build hardware	12	4	15	4	100%
Mid-term review	13	1	15	1	100%
Trip to Esbjerg, visit at MacArtney	15	1	15	1	100%
Handin specsheet and SID to MATEA 04.17 2015	16	1	14	3	100%
Test and troubleshooting	16	2	17	2	100%
Handin MATE demonstration video 05.01 2015	18	1	18	1	100%
Apply for MATE travel assistance 04.25 - 05.18 2015	18	3			0%
Bachelor, MATE technical report and NI report	19	5	19	4	10%
Seek travel assistance and plan the travel	19	7	19	3	100%
Handin MATE report, specsheet and SID 05.28 2015	21	2	21	2	100%
Handin NI report 05.29 2015	22	1			0%
MATE video monitor and tri-fold display board reque	22	1	19	1	100%
Handin bachelor report 06.04 2015 11:00-13:00	23	1			0%
Handin bachelor presentation 06.05 10:00-12:00	23	1			0%
Prepare and optimize ROV	23	3			0%
MATE compition 06.25 - 06.27 2015	26	1			0%



8 Safety

8.1 Risk Analysis

A risk analysis has been developed in order to detect the highest hazards. Those risks or hazards that have a high potential will be prevented with a plan how to eliminate them.

Risk Analysis					
No.	Potential Risk	Risk consequences	Seriousness	Probability	How to provent the risk
1	Finger inside the propeller	Hard hit on the finger	4	3	Take power of the ROV during launch and when taking it up from the water
2	Electric chock in the electronic box	Minor consequences because of the 12V, but can give a chock if the hands are wet	1	4	Turn off the power before entering the electronic box
3	Jammed hand in gripper	Scratches on the hand	2	1	Turn off the power when working on the ROV
4	Heavy lifting - When lifting the ROV alone	Back problems due to heavy lifting and upractical shape.	2	4	Two persons should lift the ROV
5	Cutting on the sharp edges	Scratch on arm and hands	4	3	Protect all sharp edges
6	ROV falls down on a foot	Hard hit on the foot, scrathes on leg and foot, blue marks	3	3	Never place the ROV on small tables also with low friction surface
7	Fuse will break	All power shuts down	2	5	Measure the current a give a feedback to the output.
8	Water leak in the elektric case	The electronic will break	4	4	Often check for water leak - Install a water sensor inside the case, that alarm when water is detected.
9	Tether plugs disconnecs	The communication and power will be lost to the ROV	2	5	Secure the plugs so they will not disconnect

Action

No.2 Dry your hands before working with the electronics and turn of the power.

No.4 At least two persons should lift the ROV.

No.5 Remove or protect all sharp edges.

No.7 Install a current sensor that gives feedback to the electronic system in order to prevent the fuse from blowing.

No.8 Install water sensors inside the case, and frequently inspect the case.

No.9 Install some unions to secure the plugs on the ROV.

8.2 FMEA

A FMEA have been developed to lay out the failure that might occur.

Here the different failures are evaluated with three different characters.

Severity How big is the consequences if this failure is occurring?

Probability How often and likely is the failure to occur?

Detection How easy is the failure to detect and how long does the failure take to fix?

FMEA - The Little Mermaid									
No.	**Funktion or Process Step**	**Failure Type**	**Potential Impact**	**SEV**	**Potential Causes**	**OCC**	**Detection Mode**	**DET**	**RPN**
1	Connecting computer to MyRio	Labview sais there is no connection	The ROV will not be able to run	4	Missing power	3	Can be seen on the ROV if there is no power on the ROV	2	24
2					Ethernet wire is not connected	1	Can be prevented with an execusion checklist	1	4
3					The plugs is damaged	1	Can be prevented with an execusion checklist	6	24
4	Sailing with the ROV	X-box controller does not respont	The ROV will not be able to run	8	Controller wire is disconnected	8	Check the connection during the run	1	64
5					Computer power is lost	5	Before starting the run, check if the power to the computer is connected	2	80
6					The controller is damaged	2	Checking the funktion during start up	9	144
7		ROV is suddenly sinking	Missing of the ROV, damaging the MyRio	10	The ROV has lost its floats	1	Checking the attachment before launching	6	60
8					Water has entered the electric case	2	The case is checked every 30 min in water. Watersensors in case will make an alarm.	10	200
9		Camera Screen is missing	The ROV cannot operate under water, but can sail towards land	5	The camera is damaged	1	Check the funktion during startup	9	45
10					The wire is broken	2	Check the tether before launch	9	90
11					The screen has lost power	5	Frequently check during the run	1	25
12					Dirt on the lince	3	Will be visible on the screen	2	30
13		The gripper is not responding	The ROV cannot finish the work	8	The gripper is broken	2	Checking the funktion before launch	8	128
14					The actuator is broken	1			64
15					The motor controller is damaged	2			128
16		Thrusters is not responding	The ROV cannot maneouvre	5	Power is lost	4	Testing funktion before launch	9	180
17					One thruster is broken	1			45
18					Motor controller is broken	2			90
19		The fuse blows	Power is lost to the system	3	Too many thrusters runs on full power	7	Power will be lost	2	42
20					Short circuit	2	Power will be lost	8	48
21	Transporting the ROV	Part will be forgotten	Unfuctional ROV	3	Forgot to check if everything was packed	5	Making a checklist to see if everything is packed	3	45
22		Damageing ROV	Unfuctional ROV	5	The ROV is not transported carefully	5	Protect all vulnerable parts	2	50
23	Launching the ROV	Damageing the gripper	The gripper will break	8	The ROV is not launched carefully	3	More than one person launch the ROV	4	96

9 Cost monitoring

Due to a tight budget, the money has at all times been monitored according to the budget made. The following diagram was used for monitoring:

ROV BUDGET													
	Granted Money	**3000,0 $**											
	Money Spend	**2216,7 $**											
	Money Left	**783,3 $**											
	Cost savings	**17,9 %**											
	Buffer	**22,1 %**									Valuta:	6,55	
Description	**Product name**	**Supplier**	**Qty**	**Unit price [input]**				**Allocated**		**Total**		**Difference**	
Registration MATE	MATE Ranger Class registration	MATE	1	100	$		DKK	100	$	100,0	$	0,0	$
Thrusters with ESC	BlueRobotics T100	bluerobotics.com	6		$	943	DKK	760	$	863,8	$	-103,8	$
Camera	Unknown	MacArtney	1		$	40	DKK	320	$	6,1	$	313,9	$
Second camera	SS-AquaCam	lights-camera-action.net	1	325	$		DKK	0	$	325,0	$	-325,0	$
Gripper	Designed	3D-printed in school	1		$	0	DKK	230	$	0,0	$	230,0	$
Screen	Dell 2007FPb	Second hand	1		$	300	DKK	150	$	45,8	$	104,2	$
Additional screen/recorder	Terratec Grabby	proshop.dk	1		$	282	DKK	0	$	43,1	$	-43,1	$
VideoSplitter	Goobay Audio splitterkabel	pc-lager.dk	1		$	19	DKK	0	$	2,9	$	-2,9	$
Tether - Power	Gummikabel H07RN-F 4 x 2.5mm^2 50meter	sanistaal.com	1		$	850	DKK	70	$	129,8	$	-59,8	$
Tether - Ethernet	Konig UTP CAT 6	MacArtney	1		$	Free	DKK	50	$	0,0	$	50,0	$
Tether - Video	Micro TV Cable 6075	MacArtney	1		$	Free	DKK	60	$	0,0	$	60,0	$
Banana plugs	Bananstik	biltema.dk	1		$	24,9	DKK	5	$	3,8	$	1,2	$
Xbox Controller	Controller	computersalg.dk	1		$	245	DKK	45	$	37,4	$	7,6	$
MyRio	MyRIo 1900	NI	1		$	Free	DKK	0	$	0,0	$	0,0	$
Bilge pump	Lænsepumpe	biltema.dk	2		$	149	DKK	0	$	45,5	$	-45,5	$
Ammeter	Amp	let-elektronik.dk	2		$	288	DKK	0	$	87,9	$	-87,9	$
Waterleakage sensor	Grove - Water Sensor	let-elektronik.dk	3		$	32	DKK	15	$	14,7	$	0,3	$
Pressure sensor		*Not yet implemented*			$		DKK	75	$	0,0	$	0,0	$
USB/ethernet converter	Gigabit LAN 10/100/1000 Mb/s	computersalg.dk	1		$	214	DKK	45	$	32,7	$	12,3	$
Floats	Pipe isulation	Bauhaus	4		$	20	DKK	75	$	12,2	$	62,8	$
Tether floats	Pipe isulation	Bauhaus	5		$	15	DKK	0	$	11,5	$	-11,5	$
Rope	Propylenrobe	biltema.dk	1		$	26,9	DKK	0	$	4,1	$	-4,1	$
Props	Misc PVC fittings and pipes	Kier.dk	1		$	976	DKK	150	$	149,0	$	1,0	$
Chassis	HDPE 500 sheet	Nordisk Plast	1		$	850	DKK	380	$	129,8	$	250,2	$
Connectors	SubConn BH6(F/M) and DBH8(F/M)	MacArtney	1		$	40	DKK	120	$	6,1	$	113,9	$
Couplings	Misc couplings	lemu.dk and dk.rs-online.com	1		$	250	DKK	0	$	38,2	$	-38,2	$
Light		*Light is included on camera*			$		DKK	45	$	0,0	$	0,0	$
Elec. Box	Watercase model 609 With Foam	Flightcases International A/S	1		$	835	DKK	150	$	127,5	$	22,5	$
					Total			**2845**	**$**	**2216,7**	**$**	**508,3**	**$**

In this list the price of the parts sponsored are not included, because the price of some of the parts are unknown:

- Video cable
- Camera
- Communication cable
- myRIO

10 Challenges

10.1 Technical

The FOV(Field of View) is unknown for our underwater cameras, which means it cannot be calculated where to place them, to get the wanted view. We also know cameras decrease in FOV when they are submerged, but not by how much. Therefore, it was difficult to predict a good mounting position. The solution was to mount the cameras above water while the live video feed was running. Then we would submerge the whole ROV, and look at the decreased FOV in water. We then knew where the camera should be relocated, making it an iterative process.

To save time we were looking for a complete gripper online. The professional grippers were too expensive, and the "just for fun" grippers were not build for underwater use. We estimated that some of the designs could be used under water, if the actuators were replaced. We could not find any actuators that was submergible, so this could not be done. Therefore, we ended up designing our own gripper with inspiration from the design we had been looking at. We designed the gripper so we could use a rotating actuator, this way we could use a bilge pump as actuator.

10.2 Non-technical

Time has been our biggest challenge throughout the project. From when we started the project in February and until the hand-in of the video was due in the beginning of May, we only had 3 months. 3 months for a small team to build a ROV from scratch, is not much. Especially since none from the team had any experience within this area of expertise. The way we did overcome this, was to evaluate the assignment from start. This way we found the key features and key components, which meant we could spend our time on the most important tasks. Time planning/time schedule was an important element in this process. The tight timeframe short time also meant we only had time to produce one prototype, and we did not have time for bigger changes or problems. Therefore, we made our design process long, so our choices could be well thought out. When we then started the process of building, every hole, wire and bracket did line up, because of our in-depth design process. This way only the software needed minor adjustments.

11 Lessons learned

11.1 Subcontractor and delivery time

One of the most repeated problems is subcontractors and delivery time. At first when we found the perfect power cable for out tether, we thought we had found the ideal solution. Later it turned out the delivery time was 8 weeks, and therefore the cable was not an option, since we would not receive it in time for the demonstration video to be made. Other subcontractors did not meet the agreed deadlines. These experiences may come from that the subcontractors do not have the same commitment to the project as we do.

11.2 Interpersonal

With a project like this it is preferred to have a company or two who supports you. It can be financially, with giveaways or by offering technical support. In the beginning, we contacted companies who we thought would have an interest in helping us. To start with, we received many rejections, but for every time we were to present our project, we got better. We learned a lot about how to contact a company in a professional manner, and what you should do to have the best chance of success. We also learned to deal with these rejections, and that a rejection should not affect the mood.

12 Teamwork

With a team consisting of only three members, it is possible to use a very flat organizational structure. We have been working very close together on all tasks, but the responsibilities have been distributed. Dennik was in charge of the structural design, Poul was in charge of software and electronics and Jens has been our handyman. Such a small team have both some pros and cons. When decisions have to be made, it is much easier to make them in a small team compared to a large team. It larger teams, people tends to learn back and work less because they do not feel the same amount of responsibility. This have not been an issue for us because of the small group and the deadlines being a constant pressure.

13 Future improvements

Since the first prototype has been developed and built in just three months, almost every part could be optimized or improved. Some parts needs to be improved more than others do, and the most distinctive improvements are:

The gripper could be optimized or maybe the complete gripper design should be rethought. It should be possible to find a better actuator than a bilge pump. The bilge pump do not always run smoothly, especially with low rpm. The design should be more rigid, and another manufacturing process should be found. The 3D-printer material is not optimal. Generally, more tools for specific missions should be developed and manufactured.

Vision is crucial to complete a task underwater. Therefore, more cameras should be mounted, and their FOV should be well considered. More viewing angels will help to counteract the missing depth perception.

The accelerometer in the myRIO should be used to program a self-stabilizing module. This way the ROV will be less prone to currents and gravity point changes, as when the ROV lifts a heavy object. In relation to water depth, our only weak spot it the rectangular electric box. If this box is replaced with a cylindrical one, our ROV could go must deeper. This would actually make it much more useable in the ocean.

14 Reflections

A large part of this project has been about electrical and software. Topics that is not part of our professional qualifications as mechanical engineers. To complete the ROV we had to get to know these subjects. Here we learned and experienced that an engineer's value is not only his knowledge, but just as much his ability to acquire new knowledge about a topic. This is a core quality of engineering, which should not be taken for granted.

15 References

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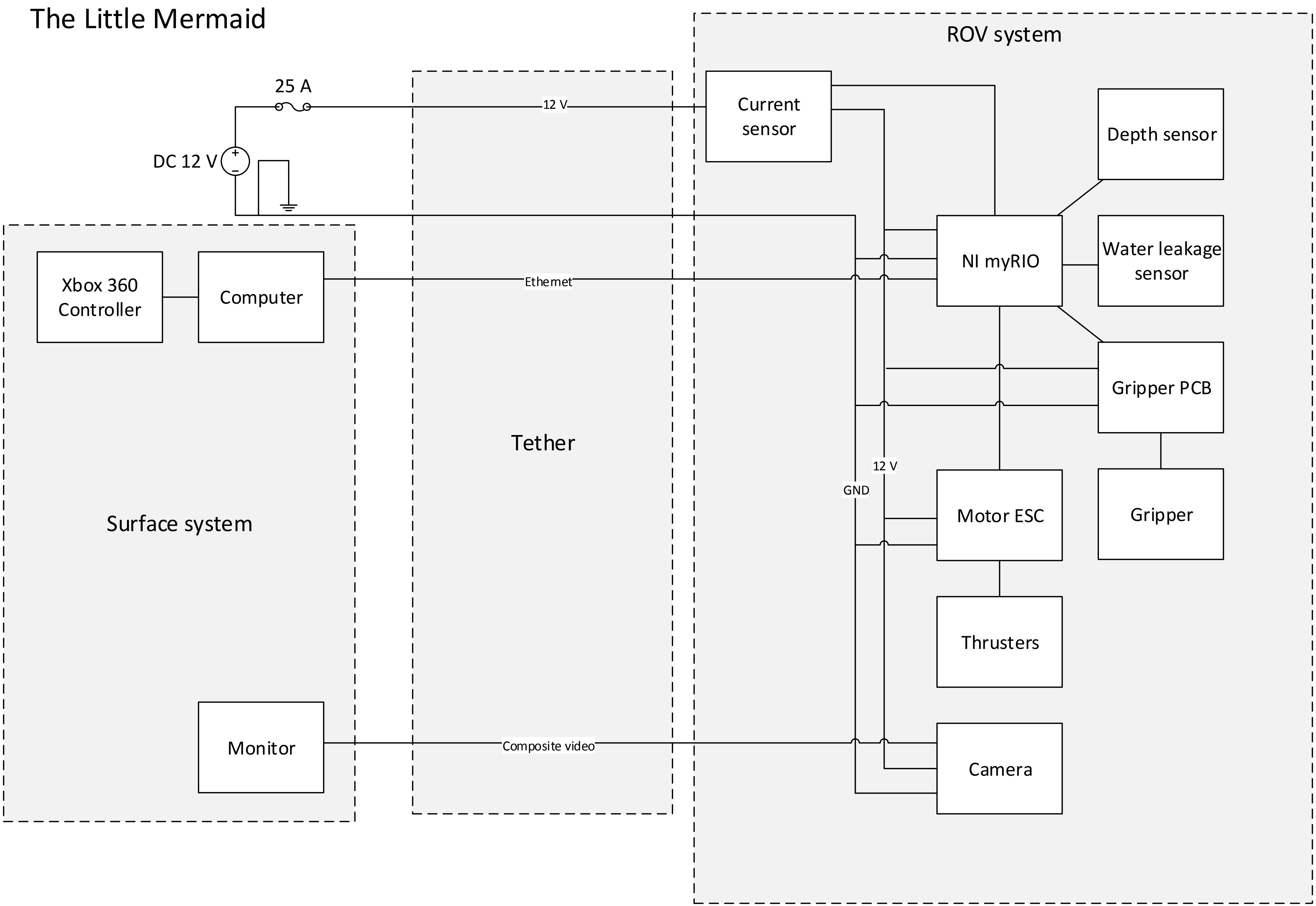
The Little Mermaid
ROV system
25 A
12 V
DC 12 V
Current sensor
Depth sensor
NI myRIO
Water leakage sensor
Xbox 360 Controller
Computer
Ethernet
Gripper PCB
Tether
12 V
GND
Motor ESC
Gripper
Surface system
Thrusters
Monitor
Composite video
Camera