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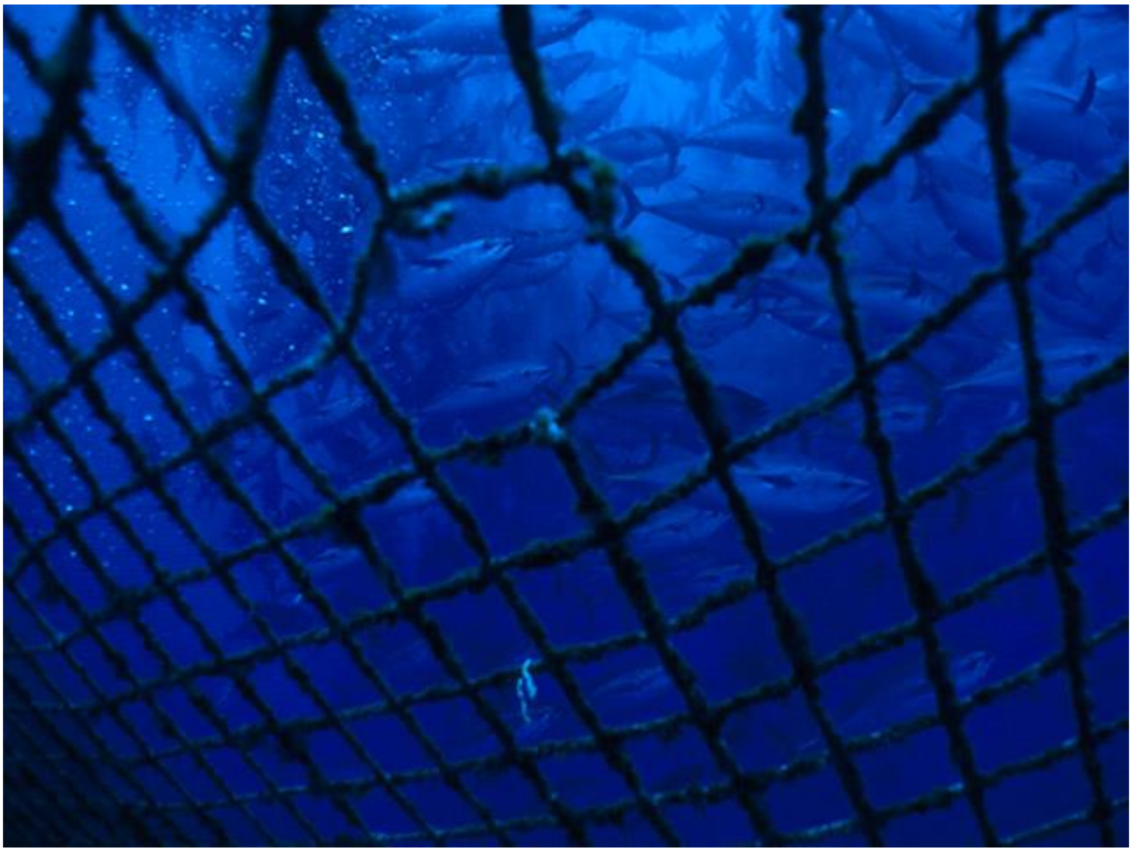
ROV Tool to Repair Fish Cages

Håkon Johan Sønstabø
Maskin, prosess- og produktutvikling



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Preface

This thesis is the final work of my 5-year Master's degree in Mechanical Engineering at the Norwegian University of Life Sciences, under the Department of Mathematical Sciences and Technology.

My interest in remote operated vehicle (ROV) technology grew after I got involved with an OpenROV acquired by the university's makerspace "Eik Ideverksted", in the spring of 2015. We aimed at improving it by making it sleeker, faster and by adding sensors measuring properties of the surrounding water.

This thesis started with the wish to look for new ways to use a ROV in the aquaculture industry. After studying the current uses of ROVs in this industry, I decided to develop a tool to help prevent the large number of fish escapes from aquaculture cages.

The project was supervised by Odd-Ivar Lekang and co-supervised by Pål Johan From, and I thank them for their help and suggestions.

I also want to thank my parents and friends for their support, their patience and help during these months.

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Håkon Johan Sønstabø

18.05.2016

Summary

This thesis deals with one of the main challenges the aquaculture industry is facing today: escapes from fish cages. To avoid or limit the impacts of such events a Remote Operated Vehicle (ROV) mounted tool is proposed and designed. This tool can fix the damaged nets rapidly before escapes can occur. The use of smaller ROVs is growing in the aquaculture industry and this thesis proposes combining an ROV as an observational platform and a repair platform.

After evaluating two different methods for the repair, one with the use of cables ties and the other with steel wire, a prototype is described, designed and evaluated. How the tool should be mounted on the ROV depends on the maneuverability of the ROV. Therefore, the degrees of freedom of the chosen ROV is important and addressed in this study.

A simulation of the drag coefficient of the tool is carried out to evaluate its characteristics in the water, followed by calculations to determine the necessary performance of the actuators in the tool.

The finished design and prototype is functional and shows promise.

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INTRODUCTION

2. Background

Aquaculture has grown fast through the last decades to become one of the largest industries in Norway. In 2014, the Norwegian aquaculture industry produced 1.3 million tons of seafood (Statistics Norway 2015). Worldwide the United Nations has highlighted the potential of aquaculture to help feed the estimated population growth to 9.6 billion people by 2050 (FAOSTAT 2014). Because the capture of wild fish is dependent on fish stock renewal, growth in the wild capture fishing industry is limited. The development of an efficient aquaculture industry is therefore necessary to increase overall fish production. Though this fast growth is not without its challenges. Some of the issues the aquaculture industry faces are dependence on wild fish feed, fish lice, diseases, escapes and pollution of surrounding waters. This master thesis will focus on addressing the escape issue.

Figure 1 Fish farm in arctic conditions

In Norway between 2005 and 2015 included, the reported escapes of the two main farmed fish, salmon and rainbow trout, are respectively 3.6 million and 0.7 million individuals. It is highly probable that an important number of escapes are not reported. Therefore, the real numbers are likely substantially higher (Fiskeridirektoratet 2016). As a result, the estimated costs of losses are high. The total value for escaped salmon was assessed in 2009 at 3.4 million euros (Jackson et al. 2015). Escapes can also cause severe environmental damages. Addressing this issue is thus essential to develop a sustainable aquaculture.

The main causes for fish escaping are structural issues. Two thirds of salmon escape are caused by holes in the net cage (Hanssen 2013). The cages are subjected to constant forces from the waves and the winds which can cause these structural failures. They can also be damaged by boats and floating debris.

Regular inspections of the fish cages are necessary to find and repair damages. Inspecting is now increasingly done with observation class remote operated vehicles. These are small submersible vehicles controlled from the surface which carry cameras, enabling an operator to inspect the nets for potential damages. When damage is found, permanent repair is generally done by divers (Thakur & Frank 2013).

This master thesis presents the development of a tool which could be used with an ROV to repair the identified holes. This could shorten the response time from damage being discovered to it being fixed and therefore greatly limit the amount of escaped fish. It would also require less resources and allow operators to focus on other tasks. This tool would therefore increase productivity and sustainability of fish farms.

3. Challenges

In this thesis a tool is developed to perform net repairs of fish cages with an observation class ROV. The following challenges are discussed and different approaches evaluated:

- What material to use in the repair: steel wire vs plastic cable ties
- Repair mechanism
- Buoyancy evaluation of the tool
- Waterproofing of electronics
- Drag calculations of the tool
- Necessary degrees of freedom for the tool to be used efficiently
- Using 3D printers to make prototypes in a short timescale

4. Fish farming

- Aquaculture or aquafarming is the breeding of sea organisms to produce food or other materials. The largest category of organism farmed is by far fish. The most common specie is salmon (FAOSTAT 2014).

4.1 History

Though the modern aquaculture industry has started in the 1970s, the beginning of fish farming is much older. It took place thousands of years ago at a time not precisely known. There are several theories regarding the first forms of aquaculture and its birth place. According to the main theories, aquaculture was first developed in inland freshwater areas (Rabanal 1988). China is often quoted as the first place where fish farming developed. Many agree that aquaculture began ca. 5000 years ago (Tidwell 2012). In various civilization, there are traces of people keeping fish in pond, lakes and seawater before capturing and eating them (Rabanal 1988).

Different types of aquaculture have progressively developed from ancient to modern times but the industrial era of aquaculture only began in the seventies. A growing demand for fish has led to an increased production by fisheries and a booming production from aquaculture, as illustrated in the figure below (FAOSTAT 2014). Due to its fast growth, the boom in the aquaculture industry is called the “Blue Revolution” by many. The term reminds of the “Green Revolution” that took place in agriculture, marked by a high increase in productivity.

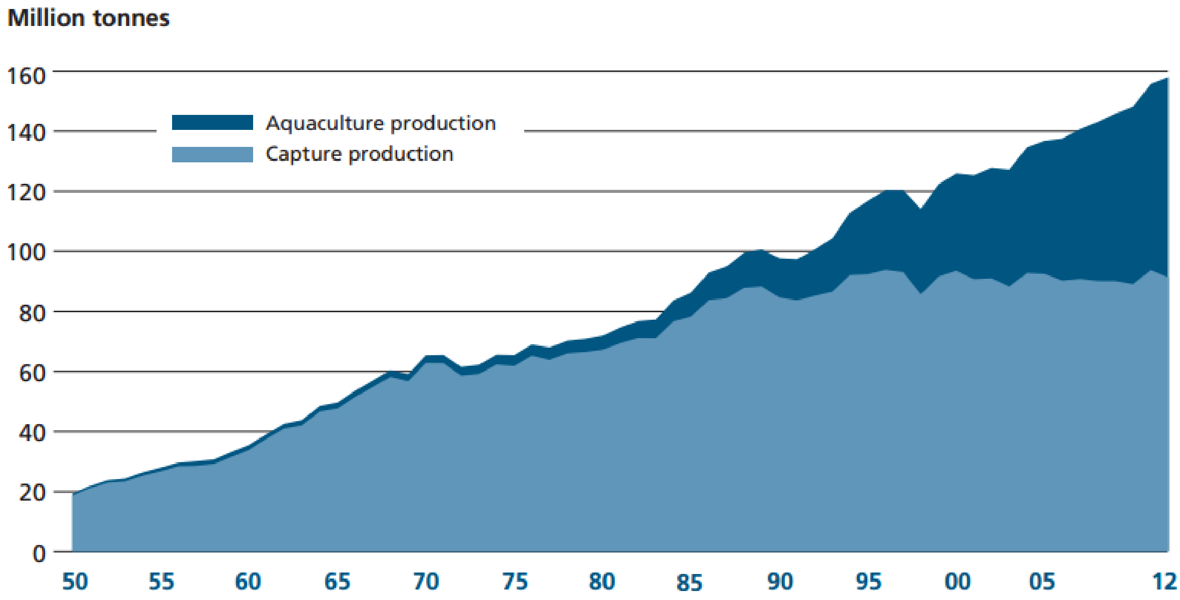

Figure 2 World capture from fisheries and aquaculture production (FAOSTAT 2014)

The trend observed in Figure 2 (FAOSTAT 2014) is seen by many as a positive development regarding sustainability. Capture production i.e. fishing cannot grow indefinitely. Unsustainable levels of fishing deplete fish resources. Overfishing has peaked in 2008 and is now slowly decreasing (FAOSTAT 2014). Fishing at sustainable levels is essential to enable fish stocks to renew. Smith (2012) argues that this environmental limit is one of the main reason for aquaculture development throughout history. Since capture production is limited, aquaculture is key to answer a growing food demand although fish farming has always faced important sustainability challenges (Smith 2012).

4.2 Production in Norway

Norway is one of the world's leader in the aquaculture industry. The Norwegian aquaculture sector could soon generate value comparable to those of the oil and gas sector. SINTEF estimated the value generated by salmon fish farming to 34 billion kroner in 2010 with an estimated growth to 238 billion kroner in 2050 (SINTEF 2012).

Norway has excellent conditions to develop aquaculture with its long coastline, rich in productive areas. Norway is the world leader in aquaculture, with a production of 1,33 million tons in 2014. It consists mainly of salmon (94.4 %) and rainbow trout (5.2 %)

(Statistics Norway 2015). Most of the production is mariculture i.e. in the ocean or in ponds filled with seawater. On the contrary inland aquaculture, which uses freshwater, is small with a production of only 85 tons in 2012, according to the FAO. They also stated that the production in Norway represented 2 % of the production worldwide (FAOSTAT 2014).

Year	2008	2009	2010	2011	2012	2013	2014
Kilotons	848	962	1 019	1 144	1 321	1 248	1 332
Million euros	2 123	2 573	3 844	3 715	4 018	5 182	5 275

Table 1 Aquaculture production in tons and value (Eurostat 2015)

Aquaculture is important for value creation in Norway. The Norwegian aquaculture is highly productive with an annual average production of 195 tons per fish farmer in 2011. As a comparison China (which produced ca. 62% of farmed food fish in 2012) only had a productivity of 7 tons per farmer and the worldwide productivity was 3,5 (FAOSTAT 2014). Higher productivity in Norway is likely to be achieved by an increased mechanization and use of robots.

4.3 Escapes

According to a literature review carried out by the Organization for Economic Co-operation and Development (OECD), 0,1 to 0,3 % of farmed salmon was lost due to escape between 2006 and 2009. The first cause of salmon escape is structural failure, accounting for ca. 40% of escapes. Then comes operational failures, causing ca. 16% of escapes and biological causes, responsible for ca. 10% of escapes. Other causes accounts for ca. 34% (OECD 2010). The causes vary depending on the species taken into consideration. Appendix 1 is a diagram of the causes for reported escape in Norway in 2015 (Fiskeridirektoratet 2015). Damages on the net is a common structural failure. In Norway, holes in the net is the most important cause for fish escape. It can be due to abrasion, biting by fish inside or outside the cage, being hit by boat propellers or failures occurring during moving of the net. As mentioned in introduction, the value of escaped salmon in 2009 is estimated at 3.4 million euros (Jackson et al. 2015). Escapes are also a great threat to the marine environment and are therefore a source of criticism of the aquaculture industry. Fish escapes damage the industry reputation and this cost might be considerably higher than the direct cost of fish escape. There is a high risk that escaped farmed fish have a negative effect on wild fish. Potential negative impacts include transfer of disease and pathogens and interbreeding (Jensen et al. 2010).

Initially fish farms were in areas sheltered from forces such as current and wind. New farms have been developed further from the coast and are therefore more exposed to such forces. Although stronger currents improve water quality, it increases the forces applied on the net (OECD 2010). The nets are consequently more likely to break and it becomes even more essential to be able to fix them.

4.4 Fish cage structure

Fish cages can be rectangular or circular. In Norway, rectangular cages have sides of 20 to 40 meters and are between 20 to 35 meters deep. Circular cages are 15 to 28 meters deep with a circumference between 90 and 157 meters. Therefore, cages volume is between 20 000 and 80 000 cubic meters. A farm often consists of 4 to 28 square cages with a distance ranking from 2 to 4 meters between cages or 6 to 12 circular cages with more than 20 meters in between (Jensen et al. 2010);(OECD 2010). The Norwegian Law allows a maximum density of 25 kg fish per cubic meters.

The size and type of the nets are also regulated in Norway. The fish cage nets can have two different types of mesh: square or hexagonal (Norsk Standard 2003). When the fish are first hatched and set out in the nets they require smaller mesh sizes to not escape. As they grow larger they can be moved to nets with larger mesh sizes.

When fish cages are exposed to high currents the structural component being subjected to the highest amount of stresses are were the floater connects with the net (Lader et al. 2008).

5. Remote Operated Vehicles

The information presented in this chapter is gathered from the book “The ROV Manual”, (Christ & Wernli 2013).

Remote operated vehicles are a subcategory of underwater vehicles. They are unmanned, instead operated remotely, connected through a tether cable to an operator on the surface. Figure 3 shows where the ROVs belong in the category of underwater vehicles. Unmanned underwater vehicles which are autonomous are called AUVs (Autonomous underwater vehicle). An ROV or AUV can be regarded as a platform to deliver sensors and tools to a location under water.

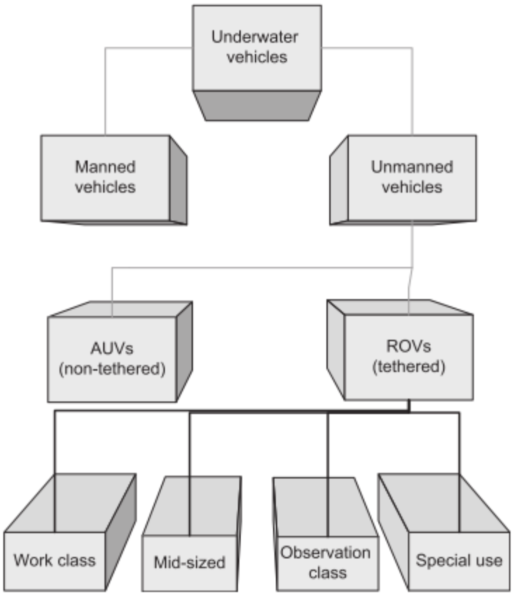

Figure 3 The family tree of underwater vehicles

5.1 Communication and power

Due to the short range of radio waves in water, ROVs must have a tether cable for communications. The tether can also have cables delivering electric and/or hydraulic power to the ROV. Smaller ROVs are often equipped with batteries onboard while the larger ones have the necessary power delivered through the tether. There are also hybrid solutions. The electric power can be in both alternating current (AC) and direct current (DC) form. For long tethers high voltage AC power is more efficient.

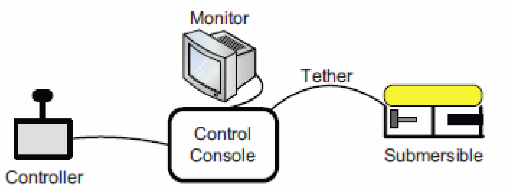

Figure 4 Components in a ROV system

The sensor and video output from the ROV go through the tether to the operator and is shown on a monitor while the inputs from the operators are given through a controller down to the ROV.

5.2 Thrusters and their configuration

The ROV needs three or more thrusters to move. Generally ROVs come in either three, four or five thruster configuration as showed in Figure 5.

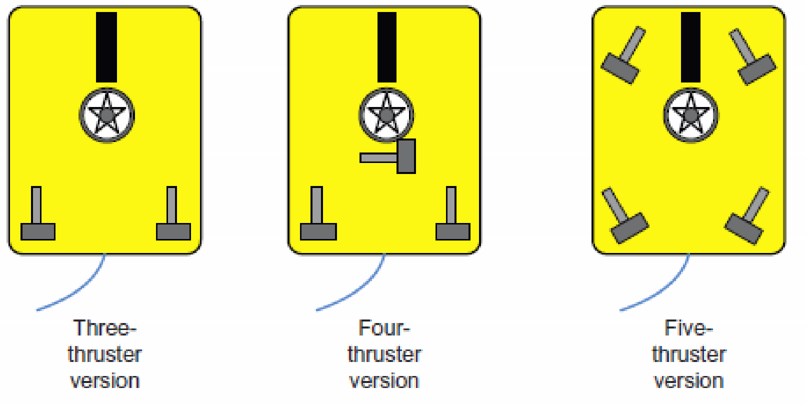

Figure 5 Thruster configuration

With three thrusters the ROV is capable of moving with four degrees of freedom. It can rotate left and right, move forward and backwards, and up and down. With a combination of all three thrusters it can also pitch its nose up or down. With the fourth thruster comes the ability to move sideways for a total of five degrees of freedom. The five thruster configuration gives the best maneuverability with six degrees of freedom, which means it can move along and rotate about all its three axes.

In order to have vertical stability in the water, the ROV's center of buoyancy has to be above its center of gravity. Therefore, the floating material of the ROV is always placed on top.

5.3 Classification of ROVs

ROVs can be categorized in four main types as seen in Table 2. The

Type	Abbreviation	Weight	Depth
Observation class	OCROV	< 100 kg	Up to 300 m
Mid-sized	MSROV	100 kg – 1000 kg	Up to 1000 m
Worker class	WCROV	1000 kg – 3000 kg	
Special class	SCROV		

Table 2 Categories of ROVs

Observation class ROVs are generally DC and battery powered, they carry a limited amount of tools and sensors. They are mostly used to inspect their surrounding with video cameras.

Figure 6 Examples of OCROVs

Mid-sized ROVs can be powered with AC through the tether which give them more power. Some of them might have hydraulic systems to be used with manipulator arms and tools, so that they can pick up and move objects under water. Due to their larger size and weight they often need cranes to lower them into the water and a system to feed out the tether as it dives down in the water.

Figure 7 Example of an MSROV

Work class ROVs are the workhorses of the ROVs. They are usually AC driven system where the electric power is transformed immediately into hydraulic power that drives the thrusters and the manipulator arms.

Figure 8 Example of WCROV

The last category of ROVs are the special types. These ROVs do not fall into the first three categories and are purpose built for specific tasks. An example of special type ROV is the towed ROVs which follow underwater cables being laid on the seabed.

5.4 Applications of ROV in fish farming

ROVs are used in aquaculture to inspect the net integrity. They can also be used to monitor the fish stock inside the nets and the quality of the water around the cages. ROVs can also carry cleaning tools to keep the fish nets clean of growths.

6. Scope of this thesis

The scope of this thesis is first to design the tool, then to make a simplified prototype in order to demonstrate the feasibility, and finally to make adjustments to the prototype after physical assessment.

7. Existing solutions

In addition to repairing net holes with the help of divers, there are currently companies delivering ROV solutions to net repairs. The extent of their use is unknown. During the research phase of this thesis, two such solutions were found and evaluated.

7.1 ROVeee

ROVeee is a company making ROV systems located in the Philippines. They make an ROV with assorted tools targeted specifically for the aquaculture industry and they claim to be "the world's first production mini ROV capable of Fish Net Repairs" (ROVeee 2015). Their solution for the repair is to use a plastic mesh with clips around the sides. One of these at the time is mounted on the front of the ROV and then simply rammed into the net with the intention of covering the damaged portion. The clips holding the plastic mesh to the net after ramming it are stronger than the clips holding the mesh to the mount of the ROV. The plastic mesh will therefore be released from the mount of the ROV and stay on the net when the ROV is reversed away from the net. This product is distributed in Norway by the company FUPE Systems AS (FUPE Systems AS).

Figure 9 ROVeee with plastic mesh mounted in front.

Weakness: It can only repair once before resurfacing and reloading.

7.2 Sperre AS

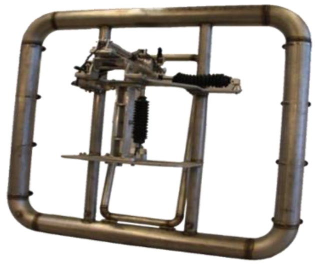

Figure 10 Sperre AS's "sewing machine"

Sperre AS is a Norwegian company located in Notodden, Norway, that specializes in ROVs. They deliver ROVs primarily to the offshore industry (Sperre AS 2015). To the aquaculture industry they deliver a so-called “sewing machine” for repairing fish nets. It works by clamping a steel ring around the damaged fish net meshes which closes the hole. To do so, it has 4 actuators. Two of them enable the clamping tool to change position in the vertical plane in front of the ROV, one is used to move the tool in and out of this plane and a third enables to clamp the steel rings. It is made of steel and aluminum, measures 1520 mm x 1420 mm x 500 mm and weighs 56 kg. The material used in the clamping rings are made of stainless steel 316 and it can hold 120 pieces of these in a magazine (Sperre AS 2013).

Weakness: Big and heavy, and requires a medium size ROV.

8. Theory

8.1 Buoyancy

Any object immersed in a fluid will experience a buoyancy force. According to Archimedes' principle: "A body wholly or partially submerged in a fluid is buoyed up by a force equal to the weight of the displaced fluid" (Tipler & Mosca 2008 p. 432). Therefore it is necessary to know the weight of the displaced fluid to find this force. It can also be found by knowing the density of the fluid, and the volume being displaced by the object. This is more practical to consider because the density of water changes with temperature and salinity and should consequently be adjusted. The difference is noticeable between fresh water and sea water. The density for seawater ranges between 1022.00 to 1030.00 kg/m^3 (Thurman 1994).

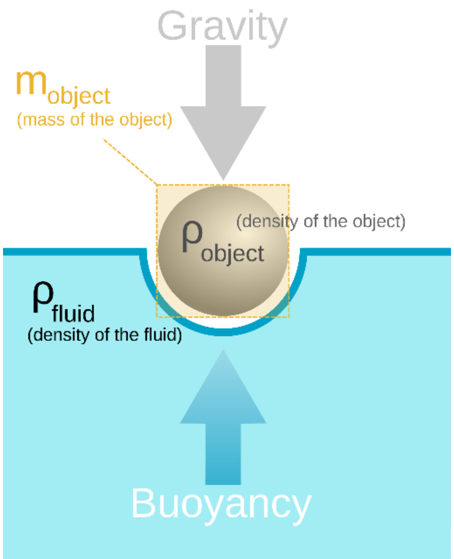

Figure 11 Buoyancy of an object

Neutrally buoyancy is the state when the average density of the object is equal to the density of the fluid it is submerged in.

8.2 Liquid pressure

An object submerged in a liquid experiences pressure due to the weight of the liquid above it. This pressure p increases linearly with the height h of the liquid above it. It also varies with the pressure of the surrounding liquid and the gravitational acceleration g (Wikipedia 2016c).

$$p = \rho g h \quad \text{Equation 1}$$

8.3 Drag force and drag coefficient

Any object moving in a fluid is subjected to a force opposite to the relative velocity due to the drag force. This force is dependent on the density of the fluid, the relative velocity between the object and the fluid, the projected area and the shape of the object. The force can be given by the following equation (Wikipedia 2016a):

$$F_D = \frac{1}{2} \cdot \rho_{fluid} \cdot v^2 \cdot C_D \cdot A_{projected}$$

Equation 2

If the force is known the drag coefficient can be found with the following equation:

$$C_D = \frac{2 \cdot F_D}{\rho_{fluid} \cdot v^2 \cdot A_{projected}}$$

Equation 3

F_D is the drag force, ρ_{fluid} is the density of the fluid, v is the velocity, and $A_{projected}$ is the projected area of the object facing the direction of the velocity.

8.4 Involute gears

Involute gears, originally invented by Leonhard Euler, is the most commonly type of gears in use. The profile of each gear tooth follows that of an involute, which is the profile you get if you unwind a string from a circle. This profile ensures that at least one point between two gears is touching while it is turning (Wikipedia 2016b). The curve of the involute can be described with the following set of equations (CADQUEST INC 2008).

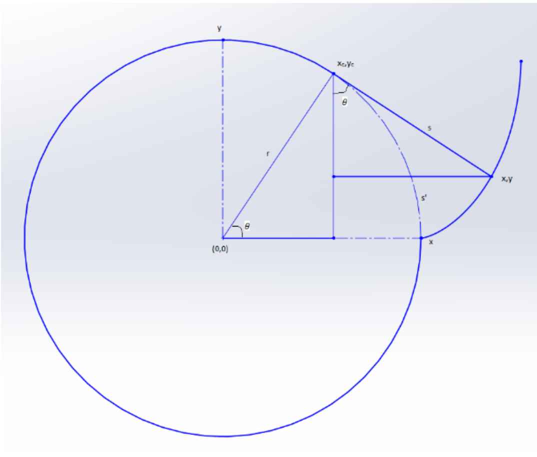

Figure 12 Geometry of an involute

$$s = s' = r \cdot \theta$$

Equation 4

$$x_c = r \cdot \cos\theta$$
$$y_c = r \cdot \sin\theta$$

Equation 5

$$x = x_c + (s \cdot \sin\theta)$$
$$y = y_c - (s \cdot \cos\theta)$$

Equation 6

The efficiency of a involute spear gear is in the range of 94% to 98% from high to lower gear ratio (meadinfo.org 2012).

8.5 Gear ratio and torque transfer in gears

The ratio between two gears, with the driven gear having z_{in} number of teeth and the output gear having z_{out} number of teeth is given as:

$$i = \frac{z_{out}}{z_{in}}$$

Equation 7

The torque being transferred through the gears change with this factor as well as the efficiency, η, of the gears.

$$M_{out} = \frac{M_{in}}{\eta}$$

Equation 8

Equations from lecture notes in the course TMP220 (Stemsrud 2013).

9. Methods

9.1 Literature study

The literature study was the first step of this thesis. This gave the foundation for the material is presented in this thesis.

9.2 CAD software

CAD modelling of the prototype has been done using Solidworks 2015. The first sketches of the prototype were made early in Solidworks to get a first impression of the general look and the possible mechanisms by moving parts in 3d space. Several ideas were considered and dismissed during this process, until one final solution was chosen. This solution was made into the prototype to be presented.

In addition to using Solidworks for modelling, the software was also used to find the drag coefficient by running a simulation. For the buoyancy calculations, all the necessary volume measurements of the parts were found through the software. This made it very easy to find the density of the completed prototype.

9.3 Rapid prototyping using 3d printers

The prototype presented in this thesis has been 3D printed. Rapid prototyping is a fabrication process where a part is build up layer by layer instead of e.g machining where material is removed (Wikipedia 2016d) This enables the building of very cheap prototypes. Access to 3D printers was provided by the Department of Mathematical Sciences and Technology at NMBU. There is a total of 11 3D printers of which mainly the Zortrax M200 has been used. The filament used in the printers is an Acrylonitrile butadiene styrene (ABS) thermoplastic. The 3D printing was essential for this thesis. It enabled the printing and testing of 3D models early in the process and moving the design phase to a more hands on approach.

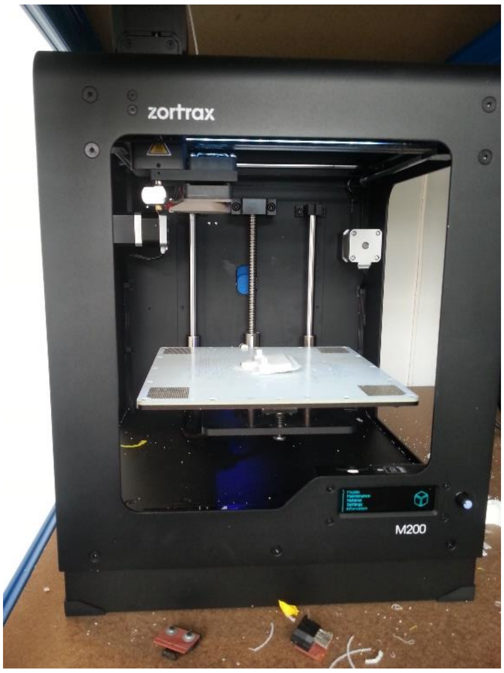

Figure 13 One of the two Zortrax M200 3d printers

DESIGN OPTIONS AND EVALUATION

10. Requirements

As previously said, it is becoming more common to use ROVs to inspect the fish cages. When damage is found, permanent fix is done by drivers. Therefore, the farm employees have to wait for a diver crew to repair the damage. Thakur and Franck (2013) have measured waiting times from 30 min to 5 hours. They also recorded that divers had to look again for the exact location of the already spotted damages (Thakur & Frank 2013).

For a repair tool to be successful in this environment, it should work with the kind of ROV some fish farmers are already using, the observation class ROVs. The larger class of ROVs that Sperre AS is delivering are far more expensive and needs more support systems. It would therefore be optimal here to have the repair tool small enough to fit on an observation class ROV.

One of the main challenges in designing an ROV is to balance the deciding parameters of the ROV. If the vehicle is made to go deep under water, it will need thick walls to be able to withstand the high pressures found there. This adds weight which in turn needs to be countered by bigger floats. These will make the profile of the ROV larger, and the drag will increase. To win over the increased drag, more powerful thrusters might be needed. This will require heavier batteries or a thicker tether cable. Heavier batteries would in turn either require more buoyancy or the thicker tether would increase the drag. This shows the delicate balance to be found in the design parameters of an ROV, and any tools attached to an ROV should be of minimum disturbance to it.

The tool should therefore be kept as small as possible and not add a lot of mass to the ROV.

11. Designing the binding mechanism

To design a tool able to quickly close around a couple of threads and then tie them together, using plastic cable ties was first considered. By moving a cable tie around a loop, the tip of the cable tie would enter the locking mechanism when it loops back in on itself and bind together what was inside the gripping arms forming the loop.

Such a solution already exists and is made by the company Panduit. Some problems emerge with this kind of solution. The complicated feeding system needs to feed one cable tie at a time to the tip of the tool. Pneumatics are used to push the cable tie through the cable leading to the tool. Precision in manufacturing would be high to allow the cable ties to correctly enter the locking mechanism every time. Which all in all lead to this idea being abandoned. Another drawback would be the amount of wasted material from the trimmed cable ties.

The other solution considered and eventually chosen was to use steel wire and twist it around the threads which should be tied together. Inspiration for this idea came from the typical plastic covered steel wire bits that is used to hold new cables together in their packaging. This kind of system would allow for a continuous feed of material with little to no waste.

12. Selection of materials

12.1 Binding material

The steel has to be able to twist easily and hold its form. It has to be able to withstand the corrosive saltwater environment. Stainless steel AISI 304 is a good candidate for this as it has able characteristics to handle sea water environment (Salleh 2013). The thread needs a plastic coating. The thread used for repair should preferably be the same color as the original net. Else some fish e.g. cods can be attracted by it (Moe et al. 2007 p. 98).

The strength of the material used in the repair should match that of the original net material (Norsk Standard 2003).

12.2 Tool body

The body of the tool should be made in a strong but lightweight material; in an ROV application this is especially important because every gram that pushes the weight over neutral buoyancy will have to be counteracted by adding low density floating material. To keep costs down a plastic composite would be a good choice. (Christ & Wernli 2013)

Plastic have good strength to weight properties and are excellent in a sea water environment. For initial development of the product the 3d printed parts proved strong enough. The material used in the 3d printer was ABS plastic. For eventual mass production this could also be a good material to use because it is very effective to produce ABS plastic parts through injection molding.

13. The prototype

Here the process of building the prototypes will be presented. Two early iterations were made before arriving at the final third prototype. The build relied heavily on the use of 3d printers.

13.1 Building the prototype, first iteration

The first printed prototype features just the two gripper arms and a base to hold them together. This was made to primarily test the function of the two gripper arms and the action of the gears that move them in synchrony. To make the gears Equation 4 to Equation 6 was modeled in Solidworks and then revolved around a little more than 90 degrees to make sure the gripper arms could move 90 degrees while still having gear teeth engaged.

Figure 14 The printed first iteration of the prototype

A simple base was made just big enough to hold the two arms together. The main goal for making this prototype was to check that pulling a steel wire through the gripper arms would work smoothly and that the gears were operating correctly.

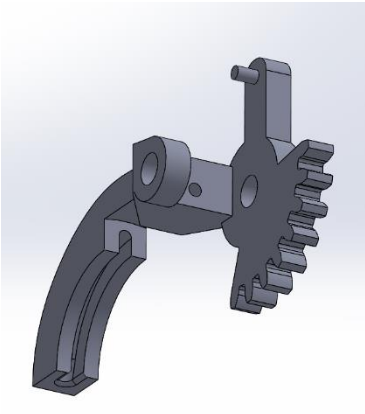

Figure 15 Details of the gripper arm

It was first thought that the servo would connect with the gripper arm with a direct linkage so on the upper gripper arm there is a protrusion for this purpose. The width of the gap between the two hinges was made wide enough to fit a spur gear that would be responsible for feeding the steel wire into the gripper. The grooves in the gripper arms have a radius of 3 mm to accommodate different sizes of steel wire. The steel wire used during testing was 0.8 mm.

13.1.1 Evaluation of the first iteration

- The action of the gears on the gripper arms worked well.
- Clearances for the pins holding the grippers were too large.
- Manually pulling the steel wire through the gripper arms worked fine.
- Issue with the arms being aligned in the closed position
- Issue with the wire being stuck in the grooves when twisting the wire.

13.2 Second iteration

In the second iteration of the prototype the twisting action of the mechanism was also printed. The shell holding everything was made bigger to accommodate this.

At this point the idea for cutting the wire was to use a dedicated actuator for the cutting action. This mechanism that would cut the wire was first thought to be placed on the

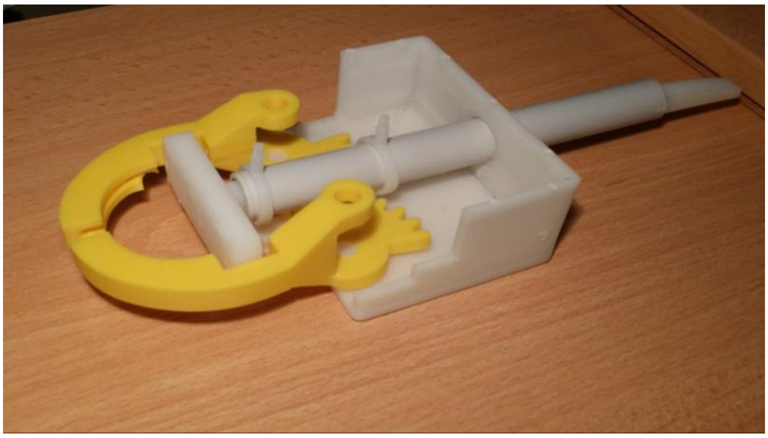

Figure 16 The second iteration

same axis as the spinning twister. This meant that a complicated mechanism was needed to translate linear motion from the axle holding the twister to rotational motion of a blade on the twister that would cut the wire.

The axle holding the twister would need to have two moving parts, which would be solved by having a solid axle inside a tube. The axle inside the tube would hold the twister and rotate. While the tube would only move linearly to engage the blade and cut the wire. After concluding this would be too complicated this idea was discarded.

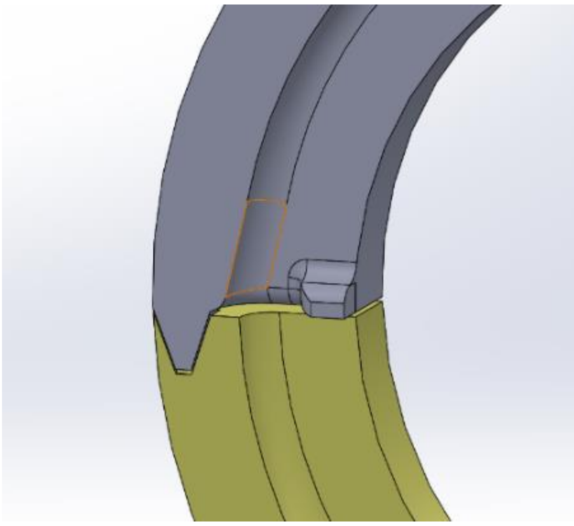

Figure 18 Cross section view of the gripper arms in a closed position.

After the steel wire has been fed through the lower gripper arm and is entering the upper gripper arm, it can get caught on the edge of the upper arm. To prevent this the beginning of the arc has been a straight line so that there a gap of about 1 mm to prevent the wire catching on the edge, see Figure 18 marked in orange. The edges of the upper arm are also rounded around the entrance for the wire to prevent this. Also seen in this figure is a protrusion from the upper gripper going into a hole in the lower gripper. This is to help guide the arms into the correct position when they are closed. Slack in the

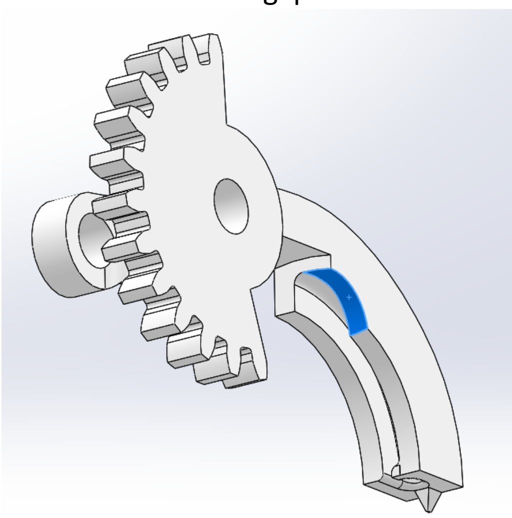

Figure 17 Cutaway marked in blue

bearing that hold the gripper arms can make the arms not close in the right position, and because of the necessary tolerances, this will be of great help.

Issue with the twisting action being blocked was solved by cutting away material in an angle so the wire can slip out of the groove as seen in Figure 17, marked in blue.

When the twisting action of the steel wire is starting, there needs to be something holding the steel wire in place and countering the torque from the twisting motion. The solution to this also needs to be able to release the steel wire when the twisting is finished. The solution to this was to put two opposing tabs on the upper and lower grippers that when closed would hold the wire and let go when they open again. One of the tabs can be seen in Figure 18.

13.2.1 Evaluation of the second iteration

- Tolerance of the hinges were much better
- Solved the misalignment of the gripper arms in the closed position
- Solved issue with steel wire being blocked
- Need space for actuators and electronics.

13.3 Third iteration

In the third iteration the casing was expanded to hold electronics and three actuators. The feeder mechanism was printed and consists of two feeder gears connected to one of the DC motors. The other motor is connected with a small spur gear to a large one for the twister axle to provide enough torque for twisting the steel wire. A servo motor was connected to a gear and then to the gripper arms. The electronics used was meant for testing purposes and came from an old RC helicopter. Figure 20 and Figure 19 shows the inside workings of the final iteration with all actuators marked in red and battery plus ESC in green. Also visible is the drum holding the steel wire and feeding it to the gripper arms through the two feeder gears. The feeder gears work by squeezing tightly on the steel wire and are both driven from the DC motor.

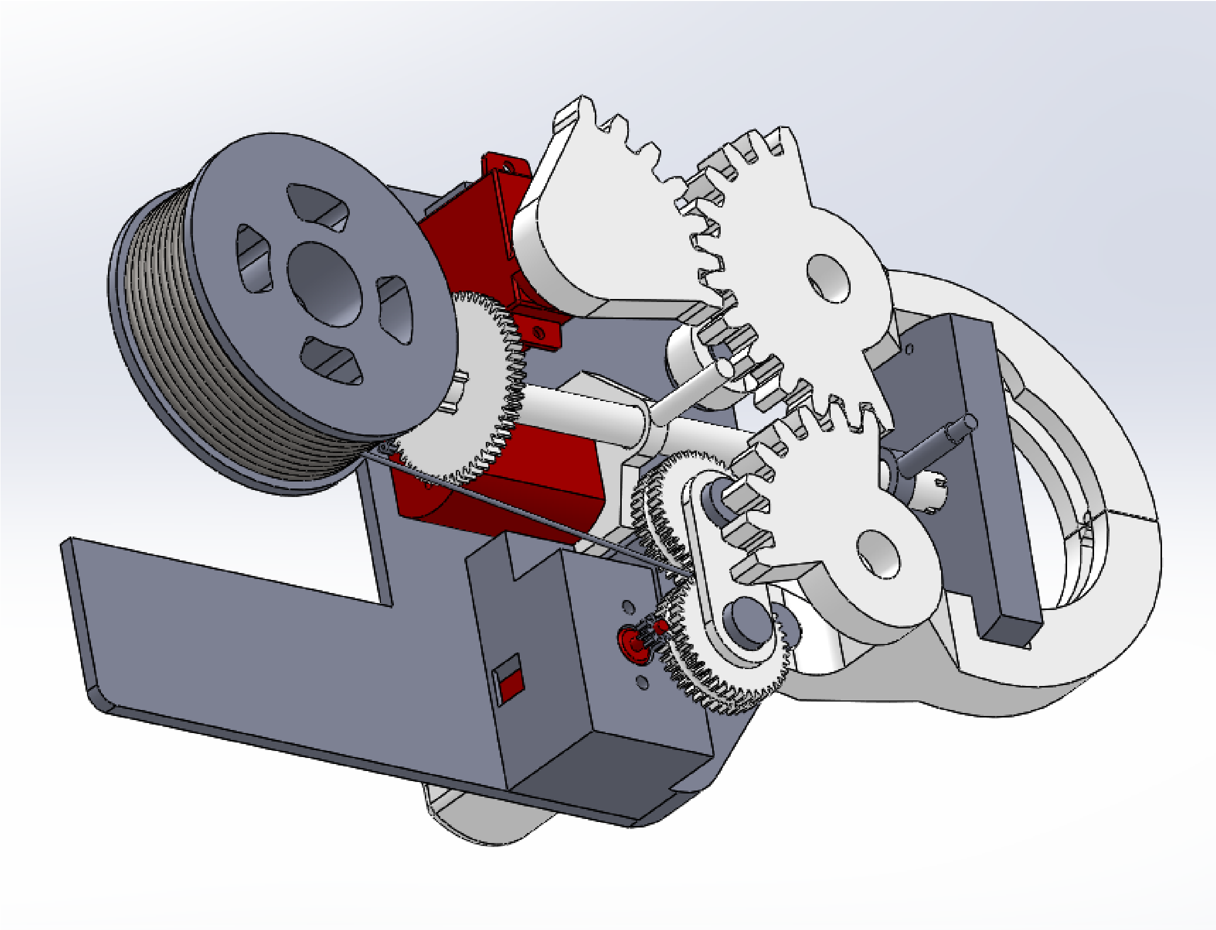

Figure 20 Inside of the final iteration

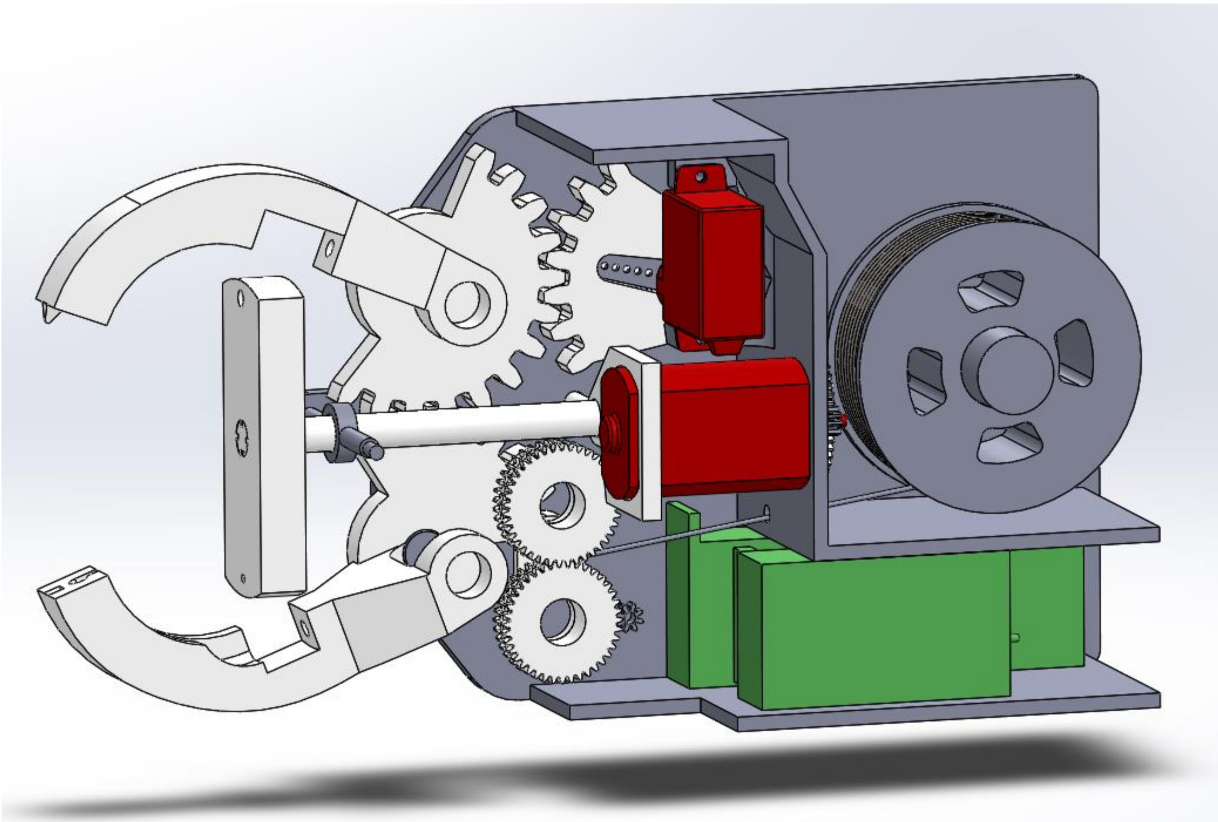

Figure 19 Shows feeding the wire, ESC and battery

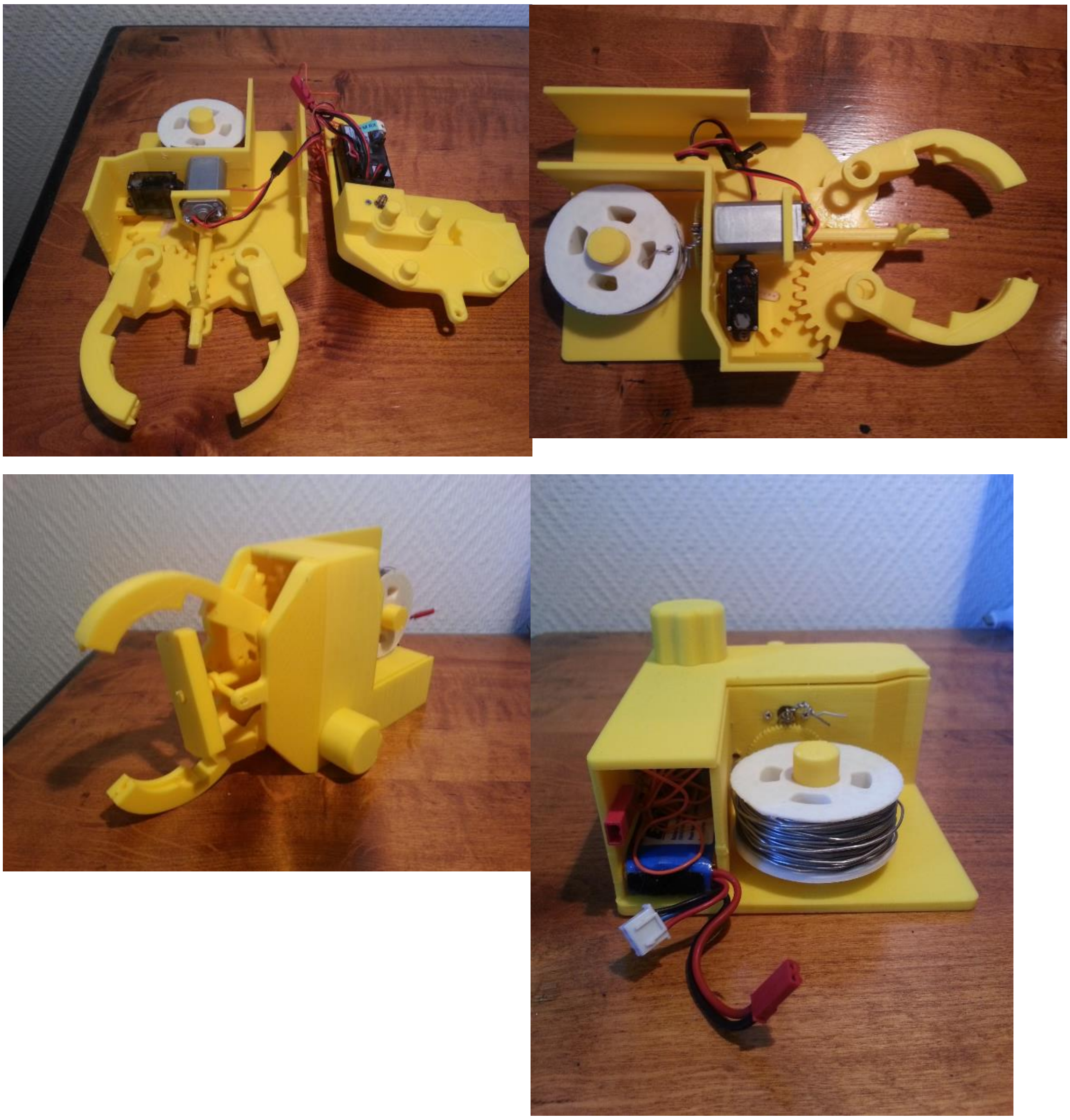

Table 3 Pictures of the finished product

Table 3 shows the finished prototype assembled.

13.4 ROV recommendation and the ROV mount

In order for the tool to be used efficiently by the operator it must be easy to move it to the wanted position by the operator. In order for this to work it and the ROV it is mounted on needs to be able to move with enough degrees of freedom in relation to the net being repaired. For the tool to be useful it should be possible to have it move along all axes of position, and also rotate around at least two, so it can pitch its nose up and down. For the tool to be able precisely get the small gripper arms into the mesh, it is necessary for the tool to be able to rotate along its length axis. Most ROVs do not have the ability to do this so this rotation should be incorporated into the mount between the ROV and the tool. Because an ROV with 3 thrusters only have 4 degrees of freedom, missing its sideways thruster, this would mean that the tool with its additional degree of freedom in the tool mount would give a total of 5 degrees of freedom. This would be very limiting to the operation of the tool and should be avoided. The ROV carrying the tool should have at least 4 thrusters giving it 5 degrees of freedom

The platform for the tool could also be a robotic manipulator arm located on the top of the fish cage. The arm could be mounted on rails around the fish cage transporting it around the cages. Such an arm could also be used to deliver other sensors or tools at the top and around the cages.

14. Results

14.1 Buoyancy calculations

To perform the necessary buoyancy calculations, we need the weight and the volume of the prototype and its components. The volumes are taken from Solidworks, while the weight is taken of the actual prototype on a scale.

ASSEMBLY	VOLUME [MM^3]	WEIGHT [GRAMS]	DENSITY [KG/MM^3]
COMPLETE TOOL WO BATTERY/STEEL	307 732	226	734
COMPLETE TOOL WO BATTERY	307 732	262	851
COMPLETE TOOL WITH BATTERY	307 732	306	994

Table 4 Result of buoyancy calculations

The results show that the prototype is close to the density of water with the battery included, which means that it is close to neutrally buoyant. This result is good because it means little adjustments need to be done on the ROV.

14.2 Drag and drag coefficient

To be able to understand how the tool will influence the ROV while in motion it is useful to know how much drag it will exert on the ROV while in motion. Mounted under an ROV, although the profile of the tool is rather slim, it would influence the characteristics of the ROV while in motion. So it would be beneficial to keep the drag of the tool to a minimum.

14.2.1 Simulation of the drag in Solidworks Flow Simulation

Using the model in Solidworks a simulation was done in order to determine the drag coefficient. The parameters of the simulation were set up as follows from Table 5.

ANALYSIS TYPE	External
FLOW CHARACTERISTICS	Laminar and turbulent
FLUID	Water
PRESSURE	202 650 Pa = 2 atm
TEMPERATURE	277.15 K = 4°C
VELOCITY	1 m/s

Table 5 Parameters of Flow Simulation

The pressure was set to 2 atm which is the pressure at around 10 meters' depth, and the temperature at 4°C which is what you would expect in the cold winter months in Norway (World Sea Temperature 2016). The velocity was set to 1 m/s which is the top speed of an OpenROV.

The projected area of the prototype tool is A = 5 449 mm², density of the fluid which would be sea water is $\rho_{fluid} = 1025 \ {}^{kg}/_{m^3}$ averagely at the surface level. The drag force was set up as a goal, so it is calculated in the flow simulation at the specified velocity. A second goal was set up using Equation 3 which gives us the drag coefficient directly.

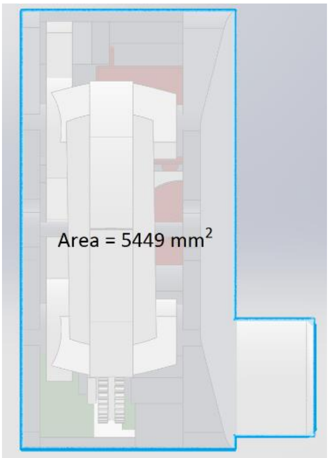

Figure 21 Projected area of the tool

14.2.2 Results of the drag simulation

NAME	AVERAGE VALUE	MIN VALUE	MAX VALUE
DRAG FORCE	2.56 N	2.53 N	2.57 N
DRAG COEFFICIENT	0.915	0.907	9.19

Table 6 Results of drag from Solidworks: Flow Simulation

The result shows an average drag coefficient of 0.915. This is comparable to the drag coefficient of a truck (Engineering Toolbox).

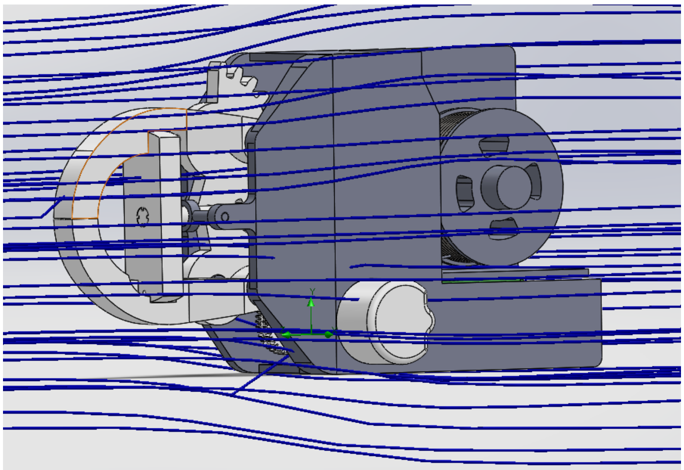

Figure 22 Figure showing flow trajectories over the tool

14.3 Opening and closing of the gripper arms

When the gripper arms close in around the broken net twines, they need to have the necessary torque to overcome the forces in the net pulling it apart, and to close together. A cylindrical fish cage with radius and height of 5 meters was simulated during a 1 m/s current and found to have 21,5 N tension in individual twines in the area of most stress (Fredheim 2005). With this as a basis for the kind of forces the tool would have to overcome, the characteristics of the actuator can be chosen.

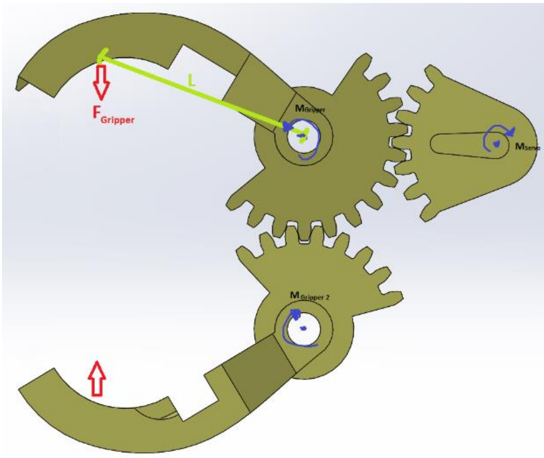

Figure 23 Forces in gripper during closing

If a series of twines break the gripper arms would have to overcome a larger force. Based on the number of about 20 N per twine, the forces to overcome should, there be damage to a series of 5 twines, would be 100 N. (If this would be too much for the tool to bite across in one operation, the operator could repair the damages in numerous steps instead.) Closing a damaged net being pulled apart with 100 N, with the distance L in Figure 23 equal to 50mm we get the necessary torque in each gripper arm to be:

$$M_{gripper} = \frac{100\ N \cdot 0{,}005\ m}{2} = 0{,}25\ Nm$$ **Equation 9**

Modyfing Equation 8 we get the necessary mechanical torque from the electric motor.

$$M_{servo} = \frac{M_{gripper}}{\eta} + \frac{M_{gripper}}{\eta^2} = 0{,}55\ Nm$$ **Equation 10**

The electrical actuator driving the gripper arms would need to deliver at least 0,55 Nm.

DISCUSSION, CONCLUSION & FUTURE WORK

15. Discussion

The use of 3d printers and rapid prototyping have enabled product designers to make prototypes quicker and cheaper than ever before. In this thesis three iterations of a prototype were made in a matter of a few weeks. This shows the tremendous help 3d printing can be in this type of work.

For the 3d printed prototype, the percentage of air trapped inside the construction between the plastic layers influences the density of the material. Because the outer plastic layers are fragile and the air inside is easily compressed, this type of construction is likely to fail under high pressure. If 3d printed material is to be used for the finished product, the outer layers should be reinforced with several layers of solid plastic around the honeycombed inside of the part.

The results of the drag for the tool was not great. This result shows that the tool will noticeably influence the ROVs motion in the water.

16. Conclusion

The aquaculture industry is promising but plagued by the problem of fish escapes. Addressing this problem is essential both for environmental and financial reasons. The net repairing tool presented in this thesis could be of great help to effectively tackle escapes.

The net fixing tool is designed to be used with a ROV. The tool was designed with Solidworks and a prototype was 3D printed.

The calculations showed that using 3D printed parts can be feasible both for strength and density requirements.

This master thesis presented a design and a prototype of ROV which could lead to substantial progress in avoiding escapes. By using 3d printing, such a tool could be produced at a very low cost and therefore be accessible to most fish farmers.

17. Future work

The groundwork has been laid to develop a functioning prototype for testing in a water environment. The initial "dry" prototype shows the concept is working and that it is worth continuing development. For the next prototype, the necessary motors and servo needs to be acquired along with the accompanying microcontroller. To be sure they fit the power requirement necessary to perform satisfactory, further testing of the energy necessary for feeding the steel wire through the gripper arms should be performed. The body of the tool needs to accommodate the exact size and fit of these new components, so some changes needs to be done of the model. Next the compartment for the microcontroller and battery needs to be made waterproofed and should be tested in a pressure chamber prior to being submerged in water.

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19. Appendix

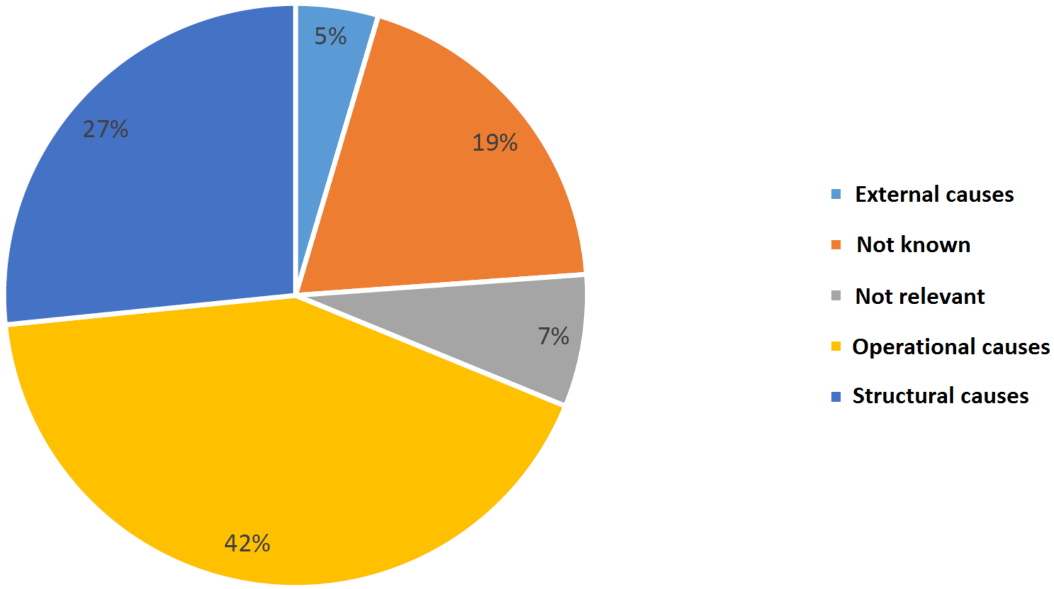

Figure 24 Causes for reported escapes in 2015 adapted from Adapted from (Fiskeridirektoratet 2015)

Norges miljø- og biovitenskapelig universitet
Noregs miljø- og biovitskapelege universitet
Norwegian University of Life Sciences

Postboks 5003
NO-1432 Ås
Norway