Streamlining seaweed farming using wireless communication

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Bachelor’s thesis in Ocean Technology

Bergen, Norway 2021

Høgskulen på Vestlandet

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IMM 2020-05

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Norsk tittel:	Effektivisering av tarehausting
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Study program:	Ocean technology
Date:	May 25th, 2021
Report number:	IMM 2021-M84 (where XX: group ID.nr)
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Antall filer levert digitalt:	15

Preface

This bachelor thesis is written at the Department of Mechanical and Marine Engineering at Western University of Applied Sciences, known as HVL in Norway, in the study program of Ocean Technology. The thesis addresses the subject of automizing a clip used in seaweed production. The internal supervisor of this project is Saeed Bikass from HVL and the external supervisor is Harald Sveier from Lerøy/Ocean Forest which is the company that assigned the subject of the thesis.

The group would like to specially thank Associate Professor Saeed Bikass, R&I Manager at Lerøy Seafood group ASA Harald Sveier, Professor and Doctor Chiara Petrioli director of innovation and founder of WSense, Assistant Professor Mathias Christian Mathiesen and Senior Engineer Harald Moen.

Abstract

The surface of the earth is 70% covered by ocean, but in 2010 only 2.5% of the gross value added came from the ocean [1]. Farming of seaweed is starting to gain importance when it comes to source of food, health products and have a wide range in industrial applications. In 2017, 145 metric tons [2] were produced in Norwegian seaweed facilities. According to a study done by Niva and Sintef that number will have grown to 20 million tons by 2050, which is an almost 138 000 multiplication compared to 2017 [3]. If the industry is going to grow this big, it goes without saying that a lot of the techniques and solutions that are being used today are going to be outdated and in dire need of a revamp.

In this project the objective is to streamline the harvesting process by developing new solutions in form of a more modern grow rope clip, which will lead to less time used on each seaweed growing facility. Over time, the goal will also want to make the harvesting so safe that it is justifiable, with regards to the safety of the workers, to move the operation offshore. Not only will these steps open new possibilities in both size and quantity, but also introduce efficiency to the system.

Different ways to improve efficiency in the seaweed farming process, with expected growth in the business in the coming years in mind were explored. The process started with researching thoroughly on what kind of wireless communication that already existed. The common denominator was that most of the underwater communication technology was massively overkill compared to the uses we needed in our system. It was considered that the technology was indeed there, but that a downgrade in the different parameters was necessary to achieve the financial limits that were set by the company. Among the parameters that can be downgraded without losing the quality contains a lower bitrate, smaller battery capacity, shorter range, and higher latency.

Several idea brainstorming sessions were completed with the goal of coming up with a detailed enough idea to make a prototype through 3D modelling and in turn, 3D printing. The total amount of ideas was at around 30, but only six of them was considered realistic and detailed enough to undergo a second evaluation. From these six ideas, one idea was constructed as the foundation to a further developing phase. This development phase started with 3D modelling using Creo Parametric. After much discussion and tinkering and finally getting a model that was satisfactory, which was in turn 3D printed.

The analysis of the 3D printed prototype showed that the mechanism of wheel did indeed work. With the knowledge extracted from the first draft of the prototype, a second, better and more optimized prototype was modelled.

Further development should include proper strength analysis on both the clip structure and the locking mechanism to ensure that the prepared solutions work in practice and not just in theory and through the prototypes.

Samandrag

Jordas overflate er 70% dekka av sjø, men i 2010 kom berre 2,5% av verdas BNP i frå sjøen [1]. Oppdrett av tare kan bli ein stor bidragsytar når det kjem som ei kjelde til mat, helseprodukt og har ei stor rekkevidde innan industrielle applikasjonar. I 2017 vart det produsert 145 tonn tare i norske anlegg [2]. I følgje ei studie gjort av Sintef og Niva vil dette talet nå 20 millionar tonn med tare innan 2050, noko som er ei auke på nesten 138 000 gongar [3]. Dersom tareindustrien skal ha ei så kraftig vekst som det blir spådd, seier det seg sjølv at løysingane og metodane som er i bruk i dag kjem til å vere utdatert og ein potensiell flaskehals.

I dette prosjektet er målet å effektivisere haustingsprosessen i tareoppdrettsnæringa for å ha løysingar tilgjengelege i møte med den massive auka som er anslått. Dette vil føre til mindre tid brukt på kvart anlegg, og har som mål å gjere prosessen så trygg som mogleg at det vil vere forsvarleg å flytte anlegga utaskjers. I tillegg til auka effektivitet, vil det også bli opna for nye moglegheiter innan båe storleik og mengd.

Det vart utforska forskjellige metodar på korleis effektivisere tarehaustinga, med tanke på den forventa auka i hausta masse. Etter ein grundig gjennomgang av eksisterande undervasskommunikasjonsmetodar, var fellesnemnaren at brorparten av løysingane var overdimensjonerte. Ein konstaterte med at teknologien var der, men at det trongst ei nedgradering innan ulike parameter dersom ein skulle ha sjanse til å møte dei finansielle grensene som var på førehand satt av oppdragsgivande bedrift. Av desse moglege parameter som kan nedgraderast utan å påverke kvaliteten er ein lågare bitrate, mindre batterikapasitet, kortare rekkevidde og høgare latens.

Det vart gjennomført fleire idéproduksjonsøkter med mål om å komme på ein så detaljert idé at det ville være mogleg å kalle det ein prototype gjennom 3D-modellering, og til slutt 3D-printing. Det totale talet på idéar enda på rundt 30, men berre seks av dei vart sett på som detaljerte nok til å bli evaluert grundigare. Ut av desse seks idéane, vart ein konstituert som fundament til ein vidare utviklingsfase. Denne fasen vart i hovudsak utført som 3D-modellering i Creo Parametric, som etter mykje drøfting og revidering gav ein modell som tilfredsstilte både gruppa og bedrifta sine krav.

Målet med analysen var å undersøkje om mekanismen til 3D-modellen fungerte på den måten den var implementert på, noko den gjorde. Ut i frå kunnskap som vart opparbeida gjennom fyrste modellen, gav ut nok informasjon til å kunne optimalisere den og komme ut med ein betre prototype.

Vidare utvikling bør innehalde ein grundig styrkeberekningsanalyse båe på strukturen og på låsemekanismen for å forsikre at løysingane som har komme fram, verkar i praksis og ikkje berre i teorien og gjennom prototypar i vennlege omgivnadar.

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Abbreviations

UWAC: Underwater Acoustic Communication

UWC: Underwater Communication

UWRFC: Underwater Radio Frequency Communication

UWOC: Underwater Optical Communication

RF: Radio Frequency

TX: Transmitter

RX: Receiver

SONAR: Sound Navigation and Ranging

DSP: Digital signal Processing

ADC: Analog to Digital Converter

DC: Direct Current

AC: Alternating Current

OSI: Open system interconnect

HTTP: Hypertext Transfer Protocol

IP: Internet Protocol

MAC: Media Access Control

FSK: Frequency Shift Keying

ASK: Amplitude Shift Keying

OOK: On-Off Keying

PSK: Phase Shift Keying

BPSK: Binary Phase Shift Keying

DSSS: Direct Sequence Spread Spectrum

IoUT: Internet of Underwater Things

UI: User Interface

ROV: Remotely operating vehicle

RC: Remote Control

1. Introduction

1.1 Motivation

Kelp and seaweed are well-known ingredients in large parts of the world, but most of the consumption is in Asia. For many years, seaweed has been cultivated and harvested to take advantage of the many benefits that can be produced and extracted from it. Kelp and seaweed are a great source for nutrition to be used in food, but also other useful substances and products like fertilizers, fish food and in cosmetics. In its most advanced form, kelp farming consists of fully controlling the life cycle of the algae. Farming the kelp has usually been labor intensive and mostly been done in Asia. However, the interest in kelp farming has started to expand to the western countries and many companies are now investing in large scale industrial farming of kelp.

Ocean Forest is a collaboration between the two Norwegian companies, Lerøy Seafood Group and Bellona. Lerøy is a world-leading seafood corporation, producing seafood corresponding to five million meals every day [4]. Bellona is an independent non-profit organization which trough identifying and implementing sustainable environmental solutions is aiming to meet and fight the climate challenges. Together they are aiming to both produce and promote kelp as an important resource to feed the growing world population, but also for the benefit of the environment. Kelp farms can be in the proximity of salmon farming reduce the environmental footprint from salmon production by absorbing nutrient salt from the fish feed and feces. Kelp is also sustainable to produce as it does not need anything else then seawater and photosynthesis to grow and it is also very good at absorbing CO_2 from the atmosphere, promoting the future possibilities to use it for biofuel.

There are however new challenges and problems to solve regarding the industrialization of kelp farming. This thesis aims to discuss one of the difficulties regarding kelp farming. Ocean Forest have given the team the subject of finding a better solution to release the growing rope from the frame where the kelp has grown during its months in the sea. The method being used today consists of manually pulling the rope up to the surface, unhooking a clip by hand, in which ties the kelp rope to the established anchoring frame of ropes under the surface, as shown in Figure 1.1 and Figure 1.2. When harvesting, this has shown to be a problematic method in regards of safety and time used. Ocean Forest wants to automate the process of unhooking the kelp rope so that they can access it easier and more efficiently. This would also benefit the possibility to produce kelp in offshore locations with worse weather conditions.

One of the challenges for solving this issue is to implement existing technology for the given scale and budget. Existing technology and equipment on the market that is used for underwater operations is mainly designed for large depths, long time in sea, long range, extreme durability which results in a steep price. It would, however, be interesting to see what the possibilities are for implementing existing technology to fit the purposes for Lerøy. Another difficult part about this project is that the clip is going to be in a very exposed and though part of the sea. It must withstand the stresses, wear and tear applied from the sea. It must also be accounted for all the growth of algae that happens in the first 10 meters from the surface as it is submerged for 5 months. Overcoming the challenges would enable Lerøy/Ocean Forest to increase production and expand their facilities as well as utilizing areas offshore.

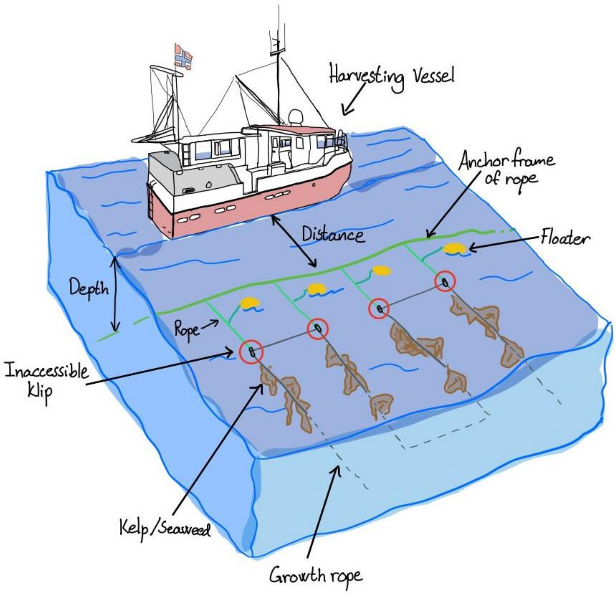


Figure 1.1: Seaweed harvesting *Figure 1.2: Overview illustration of the facility*

1.2 About Lerøy/Ocean Forest

Ocean Forest, which is a subsidiary of Lerøy, is more focused on working towards a strategy that will use more of the resources that is currently going unused. Waste product from fish production is a useable resource for production of species on a lower level in the food chain. Macro algae need nutrition salts to grow, and these nutrition salts can derive from fish production like salmon farming. Because of this recycle, the unused resources in the environment surrounding the facility can be recovered and be put into other uses.

Figure 1.3: Ocean Forest inspecting a facility ©Marianne Alfsen/Felix Media [5]

The vision of Ocean Forest is to substantially multiply food production from the sea in a sustainable manner by harvesting species from lower down in the food chain. is to be the leading and most profitable global supplier of sustainable seafood of highest quality. Ocean Forest expresses that introduction of integrated aquaculture on a commercial scale can realize the vision that aquaculture in the future where one expects to meet an increased demand for food and renewable energy.

Figure 1.4: Sugar kelp being harvested ©Marianne Alfsen/Felix Media [5]

Ocean Forest collaborate with specialized experts to evaluate potential challenges related to time of year and different organisms that grow around the farms, and to chart the positive and negative impact of the surrounding aquaculture. Ideally, a joint facility between the salmon farmers and the seaweed farmers will supplement each other in a way that the seaweed absorbs the nutrient salt that contributes to an increased growth in the seaweed [6].

1.3 Objectives

Main objective:

The main objective is to search for, and possibly develop a solution for wirelessly and automatically unhooking a clip which attaches the kelp growing rope to its anchoring frame of ropes.

It is decided that developing the mechanism itself that grips around the rope and releases with an electrical signal is the task of most importance.

Detailed objectives:

Sub objective 1: Find out the necessary properties and criteria for the clip that makes it suitable for kelp and seaweed production.

Sub objective 2: Assessing existing communication methods for use in water/sea.

Sub objective 3: Research and assess what components are needed, their availability and compare them to each other.

Sub objective 4: Find out about and decide which underwater communication technique is best suited for this case.

Sub objective 5: Develop a user-friendly solution and protocol for the seaweed reaping process with the automated system.

Sub objective 6: Develop a design for the user interface.

Sub objective 7: Brainstorm ideas for the mechanics of the clip and evaluate them against the needed properties and criteria.

Sub objective 8: Further development and engineering and 3D-modelling of the best ideas.

Sub objective 9: Optimize the design and strength based on analysis in Ansys.

Sub objective 10: Make a prototype for real life testing.

Sub objective 11: Summarize the project and results from testing.

1.4 Requirement list

Some requirements were noted and discussed early in the process. This became a foundation for what to look for when doing research and continuing with the design and engineering.

D/W	***Requirement***
	1. Design
D	Have a strong enough grip around the growing rope to prevent slipping
D	Compact and efficient design that can contain the needed components
	2. Communication
D	Ability to open and release the clip from a distance
D	Have no conflict appear with being adjacent to 300+ other units
D	Use a binary addressing array, no high speed or low latency required
D	The signal should be able to transmit at 100+ meters with no problem
	3. Material
D	The chosen material of the clip must be able to handle the maximum load
D	Withstand a five month submerge corrosion

D/W	*Requirement*
W	Consist of a material that does not corrode, ie. plastic, coating
	4. General
W	Low cost
D	Be independent of an attachment in the growing rope

Table 1.1: Requirement list

1.5 Scope of work

The first step for this thesis is to understand the subject and assess what information and knowledge that the team already possess. Accordingly, a process of generating a main objective followed up by sub objectives for completing the main objective is put into action. During this process, gaps of knowledge and missing information will come to light. The next part of the thesis is to research, learn and gather relevant knowledge and information that is needed to complete the objectives. Once the team is confident in their knowledge and abilities for solving the main objective, it can start evaluating solutions and more importantly weed out the not as good solutions from the good solutions.

When there is a proposal for a final solution, a process of assessing how the solution is overcoming the challenges would be necessary. If the solution still holds up, it could be refined and presented as a solution for solving the main objective. It should be discussed if the solution could be tested, if there are issues with the solution that could be a problem in the future, how the solution should be implemented and possibilities for improvement and further development.

2. Literature Review (Theoretical approach)

There are many ways to approach the main objective of a thesis. Various technologies have emerged from the science of underwater acoustics since Leonardo da Vinci first discovered it in 1490. Communication and data transmission both in air and under water are essential topics of the modern world and the technology has advanced throughout the 20^{th} century.

This chapter aims to convey the theory regarding the different wireless communication methods that exist today, and what methods that are available to disposition in this specific system layout. In addition to this, also to cover what solutions are suitable with regards to parameters and requirements that have been established for this system.

2.1 Types of wireless communication

It was quickly assessed by the team that a crucial part of solving the stated issue of the thesis was to figure out the automation part firstly. The group concluded, after some discussion with the company, that an electrical wireless underwater solution was the most feasible option.

2.1.1 Underwater wireless optical communication (UWOC)

Underwater wireless optical communication is a method of underwater communication which is used in ranges from 10m – 150m, with a potential for reaching as far as 500m, but when passing the 100m mark the bandwidth drastically drops [7]. Since the absorption and scattering of optical waves is significant in water, UWOC has not been a common choice, but in later years the discovery of lower absorption in the green/blue zone in seawater has made UWOC more suitable as a communication option in shallow seawater. UWOC is being used on subsea installations such as wellheads for the oil and gas industry. UOWC can deliver data rates as high as Gbps over short and medium ranges because of its large availability of bandwidth [8].

The transmission is low latency because of the high speed of propagation of optical waves in water. This makes the use of UWOC a good alternative for images, real-time videos, high performance sensor networks, etc. because of their requirements for high-speed communication and high data transmission. However, because of the degradation effect of UWOC channels when it comes to absorption, scattering, turbulence, dispersion, etc., the use of UWOC is limited to distances up to 100m with a practical transmission power and is most often used between 1-15 meters. Another issue with UWOC is that the equipment must have a direct line of transmission between them without any objects obscuring the signal path. Therefore, growth on the equipment becomes a problem and a burden to clean especially in the upper layer of the sea, where photosynthesis is most intense.

2.1.2 Underwater wireless RF communication (UWRFC)

Underwater wireless radio frequency communication, UWRFC, is a way of sending electromagnetic waves under water. This gives it the benefit of having good data transmission rates, up to 100 Mbps in very close range, moderate latency, and minimal propagation delays. Electromagnetic RF is capable of transiting both the water/air boundary and the water/seabed boundary as well as passing through ice. It is also unaffected by water depth and turbidity/bubbles as well as multi-path propagation. The disadvantages with UWRFC have been its very limited range. The attenuation is dependent on frequency and conductivity, which leads to UWRFC being heavily dampened since water is one of the materials with highest permittivity.

To achieve a significant range with UWRFC, low frequencies must be used, which drops the data transmission substantially. It is also susceptible to electromagnetic interferences and there are issues with power consumption, weight and the size of the TX and RX units. Another disadvantage with UWRFC technology is that it still in an experimental stage and has not yet reached the state of being sufficient to be used commercially in products. There is however a great interest in researching in

UWRFC to make it more appliable as a solution for UWC, such as antenna design with impedance-matching antenna enclosure that will reduce the size of the antenna whist improving transmission[9].

2.1.3 Underwater acoustic communication (UWAC)

Acoustic communication is the most common method of wireless communication underwater. One important reason is that sound can travel far in water compared to UWOC and UWRFC technologies. Historically seen, the study of sound propagation in water has proved to be useful since sound is a known biproduct from lots of human and animal behaviour such that it could be used for listening and estimating a distance from the sound source. Later the development of both passive- and active SONAR (Sound Navigation and Ranging) used the echo principle to establish a measurement of distance. And finally, the use of digital technology makes it possible to use sound waves to send binary data.

Today, lots of equipment utilizes UWAC because of its good range, energy efficiency, small size, and cost. It is used for many applications such as telemetry for environmental monitoring, basic communication between submerged devices and certainly in acoustic release devices. UWAC is well known for being able to reach up to 20 kilometres range and even longer. There are however some challenges and issues with the use of UWAC and how it propagates in water, many of them described in [10], [8]. The speed of sound waves in water and its channel quality is affected by many properties of the water medium itself, such as temperature, pressure, and salinity. The attenuation is directly proportional to the frequency and depth of the water medium and is caused by absorption of acoustic energy, scattering, refraction reverberation and dispersion. Other issues are path and multi-path propagation losses, doppler frequency spread, geometric expansion, and ambient noise. UWAC have a better range vertically than horizontally and has been difficult to use in shallow water.

Compared to electromagnetic waves such as used in UWRFC, sound waves travel much slower. These issues result in UWAC having a high latency, low available bandwidth and therefore a slow data rate. UWRFC can also transmit through the water/air boundary which UWAC cannot. There has however been technological progress with UWAC, and researchers have developed sophisticated methods and algorithms to improve UWAC, such as orthogonal frequency division multiplexing which is used to achieve higher data rates.

2.1.4 Comparison

The following table presents the properties of the different applicable communication methods existing today [7], [8], [10].

Parameter	***Acoustic***	***RF***	***Optical***
Range	Several kms	Up to about ≈ 10m	≈ 10 – 100m
Latency	High	Moderate	Low
Bandwidth	1 – 100 kHz	≈ MHz	10 – 150 MHz
Speed	1500 m/s	≈ 2.255 x 10^8 m/s	≈ 2.255 x 10^8 m/s
Attenuation	Distance and frequency dependent (0.1 – 4dB/km)	Frequency and conductivity dependent (3.5 – 5dB/km)	0.39 dB/m (ocean) 11 dB/m (turbid)
Data rate	~ Kbps	~ Mbps	~ Gbps
Frequency band	900 Hz – 60 kHz	30 – 300 MHz	5 x 10^{14} Hz

Parameter	*Acoustic*	*RF*	*Optical*
Transmission power	< 1W – 10 W	Few mW to hundreds of Watts (distance dependent)	Few Watts

Table 1: Communication methods comparison

2.1.5 The most suitable method

For the main objective that this thesis focuses on, one method of UWC must be selected. The chosen technology is UWAC because it is a relatively cheap and proven technology. It has potential to be better with advanced modulation for use in shallow water. It is also compact and the only one that easily achieves sufficient range without using much energy to do so.

2.2 Components

2.2.1 Acoustic modem technology

In Figure 2.1, the three most major components needed are pictured. It consists of an underwater transducer, an analog transceiver, and a digital hardware platform.

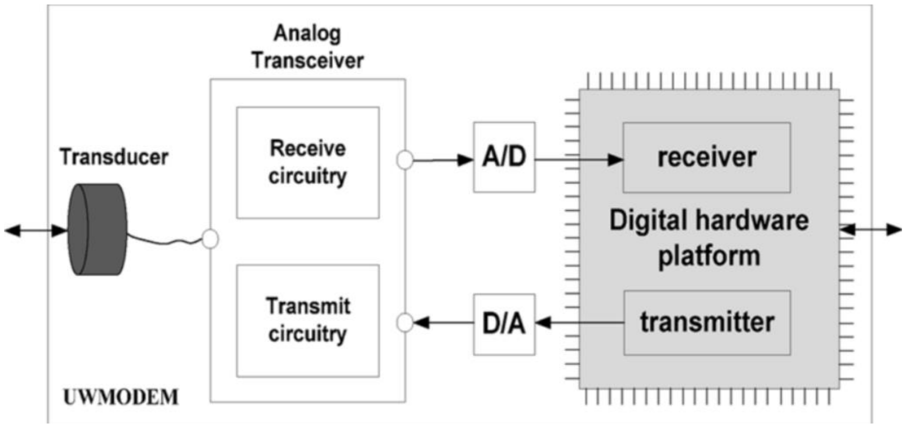


Figure 2.1: Components in an underwater modem [11]

2.2.2 Transducer

Ultrasonic transducers are typically made from a piezoelectric material that generate an electric potential in response to an applied mechanic stress in a form of a sound wave etc. When underwater, the crystal needs to be encapsuled in some sort of watertight housing to prevent any contact with conductive fluids. It is also important to consider that the transducer must have a matching layer between the transducer itself and the medium in which it is transmitting and receiving, much like a gel is used for medical ultrasound examination. Most commercial transducers are too expensive because of the short-range needed in this setting. This is enlarged by a low volume production. This is where the low-cost raw piezoelectric soars when compared to the commercial transducer.

Transducers are usually omnidirectional in the horizontal plane to reduce reflection along the surface and off the bottom. This is an important aspect in this case because of the placement of the transducer is going to be in shallow water.

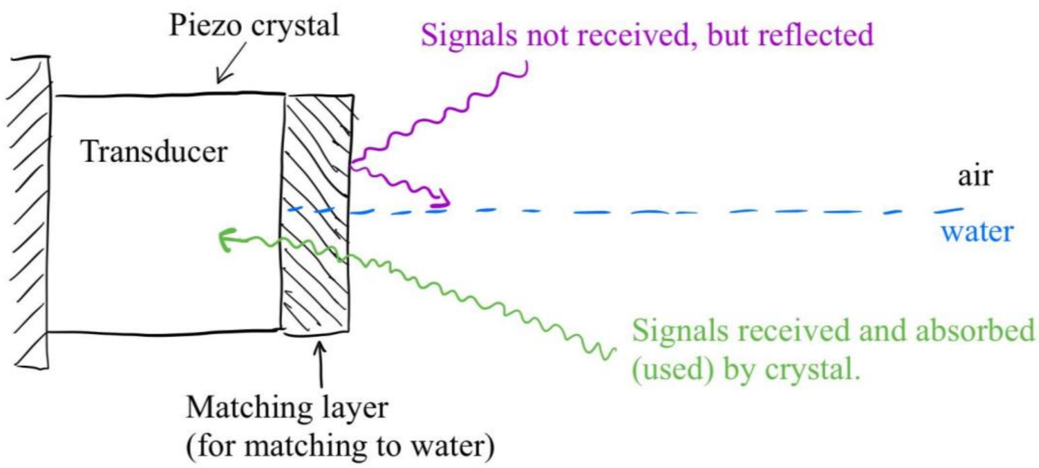


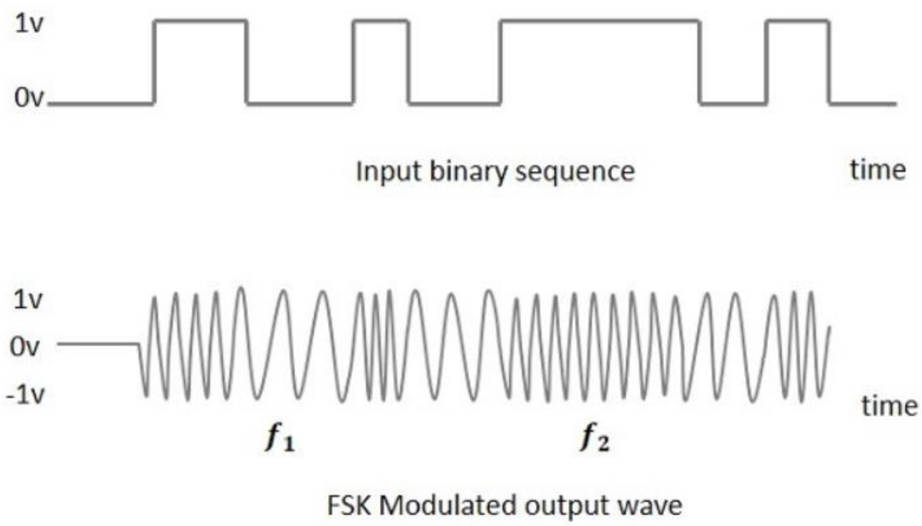
Figure 2.2: Transducer illustration

2.2.3 Analog transceiver

Consists of a transmitter and sensitive receiver both of which are optimized to operate in the transducer's resonance frequency range. The transmitter is responsible for amplifying the signal that is coming from digital hardware platform and sending it to the transducer.

2.2.4 Digital transceiver

The digital transceiver is responsible for physical layer communication. This includes modulation,



filtering and synchronization When designing a digital transceiver, the choice of modulation scheme and hardware platform. Frequency shift keying is as mentioned earlier, a simple modulation scheme that is favored in due to small bandwidth and has been widely used in underwater systems because of the resistance it has with regards to time, but also because the frequency spreading of underwater acoustic channels.

Figure 2.3: Modulated FSK output [12]

2.2.5 Digital signal processor

Digital signal processing (DSP) is a mathematical manipulation of an input signal like audio, temperature, or voice. This information can then be represented into the discrete from one for it to be digitally processed. An analog-to-digital converter is need where one takes analog signals like light, sound etc. and convert them into binary, a digital format so that computers can read of it. Electric equipment. AD-DA are essential components for any variation of a digital signal processor. An example where the ADC converts the analog signal collected by an input to audio equipment into a digital signal that is outputted by a speaker is a regular microphone, as seen in Figure 2.4 [13].

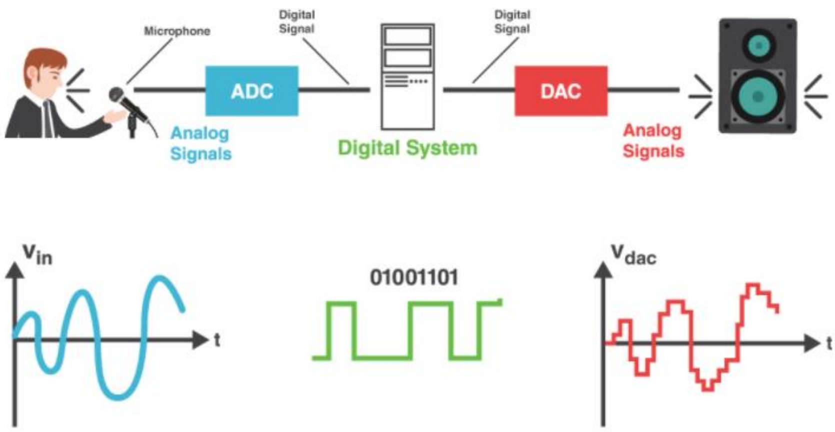


Figure 2.4: AD-DA system [13]

2.2.6 Common electronic actuator circuits

A couple of the most common electronic devices for performing a mechanical task was assessed early in the process. This would prepare the group to have them in mind when designing the mechanism later on.

Stepper motor

A stepper motor is a motor powered by electricity and gives rotation when given an electrical current. They usually come in a rather small size, so that the amount of power needed to operate them are kept as low as milliampere but does also exist in a variety of sizes. The rotation of a stepper motor is kind of discrete, unlike an DC motor which is gives a continuous rotation. It is possible to get close to a continuous rotation with the stepper motor, but it requires a waveform with more finesse [14].

When the first electromagnet is powered on the gear-shaped iron will align with the teeth on the electromagnet, offsetting the gear-shaped iron from the next electromagnet. Then the first electromagnet is turned off and the next is turned on. The gear-shaped iron will then align with the electromagnet which was turned on and the rotation has started. For further rotation, this process will continue for as long as an electrical current is given to the stepper motor. Each rotation is called a step. Since a full rotation requires a certain number of steps, the stepper motor can rotate at precise angles [15].

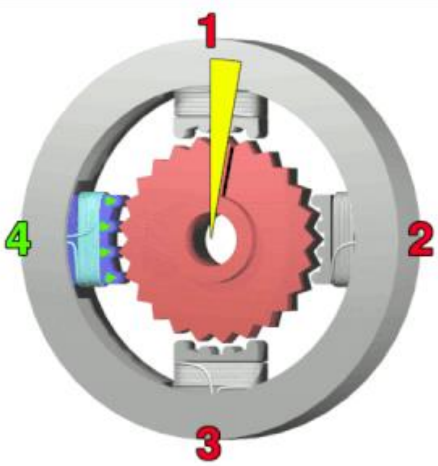


Figure 2.5: Stepper motor [15]

Servo Motor

A servo motor is a closed-loop mechanism that uses feedback to control its motion. The motor uses an encoder to receive feedback about the position and speed. In the more simpler servo motors only the position is tracked. The position received from the encoder are compared to the position given from the input. If the positions do not have the same values, an error will occur. This makes the motor rotate until it`s the input position and the output position are the same.

Linear actuator

Linear actuators create a linear motion from a rotating motion using a leadscrew. A nut is moving upwards or downwards depending on the direction of the rotation. This is how the rotating motion transfer into linear motion. They are usually run by an AC or DC motor. The speed and force depend on the gear ratio, which means that the relation between force and speed inversely proportional. The more force needed, the bigger wheel is needed, and this results in lower speed, and vice versa [16].

2.3 Open System Interconnect (OSI) model

The OSI model is a seven layered network model, which is illustrated in Figure 2.13, and is considered a must have fundamental basis when it comes to organizing different types of networks. The model itself is designed to achieve data transmissions between systems and networks Its goal is the interoperability of a diverse communication system with standard communication protocols. The OSI model makes it possible for human-readable information to be transferred over a network from one network to another, because the data travels down on the sending device, and then travel up on the receiving end.

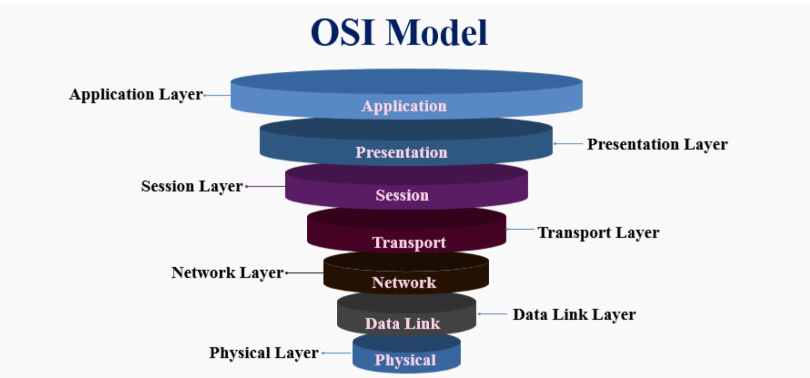


Figure 2.13: Open System Interconnect model [17]

7. Application Layer

The first layer is the application layer where the transmission and reception of unstructured raw data between a device and a physical transmission medium. This layer converts digital bits and inputs into electrical, optical or radio signals. This is the only layer that directly interacts with data from the user and software applications like web browsers and email clients are examples of this. Application layer protocols include HTTP/HTTPS which is the communication protocol on the internet.

6. Presentation Layer

The second layer of the model is the presentation layer. It receives data from the application layer in the form of letters and numbers and turns it into understandable binary format for the application layer. The presentation layer is responsible for translation, encryption, and compression of data. Two devices communicating with each other may be using different encoding methods, so the presentation layer must make sure that the data is understandable for the application layer.

5. Session Layer

Session layer is the third and it helps in setting up and managing connections enabling, sending and receiving data followed by terminations of connections or sessions and close it when needed. The time between when the communication is opened and closed is known as the session. The session layer makes sure that the session stays open if needed to transfer the data and then closes it to not waste resources. The session layer also offers a checkpoint system, so if an error occurs after transferring 90 MB of data, instead of starting at scratch you continue from 80 MB.

4. Transport Layer

Below the session layer, the transport layer can be found. This is responsible for the end-to-end communication between the two devices. This includes taking data from the session layer and breaking it up in pieces before sending it down to layer 3, the network layer. The receiving side of the transport layer is responsible for reassembly of the data that the session layer can comprehend. Flow control and error control is also the transport layer responsible of. The flow control determines the optimal speed of the transmission to ensure a fast connection.

3. Network Layer

Next in line is the network layer. This is responsible for creating and maintaining a connection between two different networks. The network layer breaks up segments received from the transport layer into smaller packets on the sender's device and reassembling these mentioned packets on the receiving device. The network layer also finds the best physical path for the data to reach its destination.

2. Data Link Layer

The data link layer is very similar to the network layer, but its boundary is to transfer data between devices on the same local network. It receives data packets from the network layer which contains IP-addresses of the sender and receiver. There are two types of addressing: logical and physical addressing. Logical addressing is done at the network layer where senders and receivers IP-addresses are assigned to each segment to form data packets. Physical addressing is done at the data link layer where MAC addresses of sender and receiver are assigned to each data packets.

1. Physical Layer

Up until now, data from the application layer gets segmented by transport layer and placed into packets by the network layer and framed by the data link layer which is a sequence of binary 0s and 1s. The physical layer converts these binary numbers into signals and transmits them over local media.

2.4 Signal modulation methods

This chapter includes some of the most common techniques for signal modulation.

2.4.1 Frequency shift keying

Frequency shift keying (FSK) is a digital modulation method that changes the frequency within the frequency content. The signal that is being transmitted are binary and are encoded before modulation. Within digital communication this is an important task, where excess bits are added to raw data which helps the receiver detect bit errors during transmission and then fix them [18].

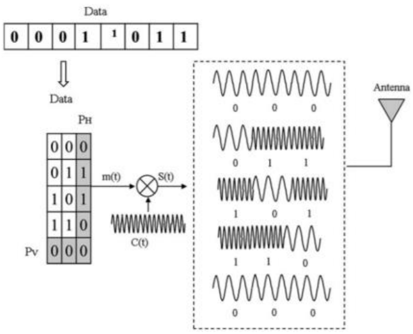


Figure 2.6: Frequency Shift Keying (FSK) modulation [18]

Once the binary data has been transmitted, the data need to be received and demodulated. This is done by using band-pass filters. When using binary FSK (often called FSK) two band-pass filters need to be used. They need to be set according to the frequencies from the carrier and the deviation. When the signal enter the receiver it goes through the respective filters before the corresponding bit is made [18].

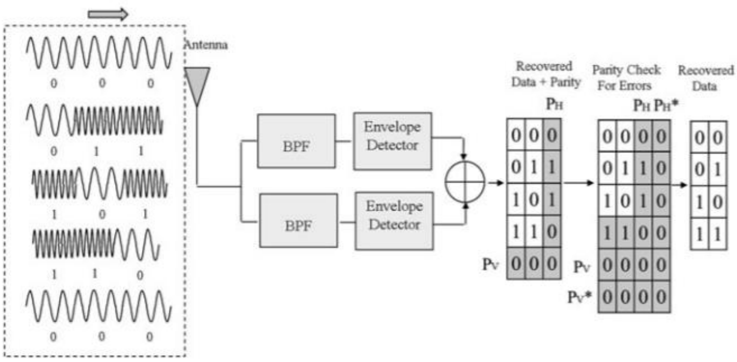


Figure 2.7: Binary FSK detector utilizing two match band-pass filters [18]

2.4.2 Amplitude shift keying

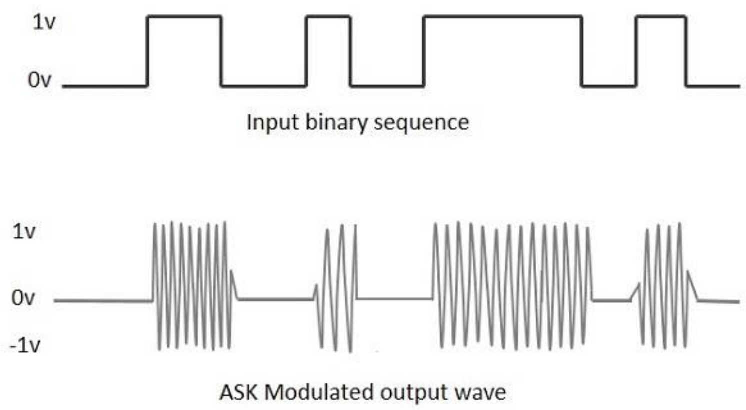


Figure 2.8: ASK waveform [19]

Amplitude shift keying (ASK), often referred to as on-off keying (OOK) changes the amplitude of the carrier, but unlike FSK the frequency stays the same [20]. The signal that is being modulated and transmitted are binary and are encoded before modulation. In digital communication this is an important task where unused bits are added to raw data which helps the receiver to detect and fix bit errors if they occur. Fig 2.9 shows how an ASK modulation works [20].

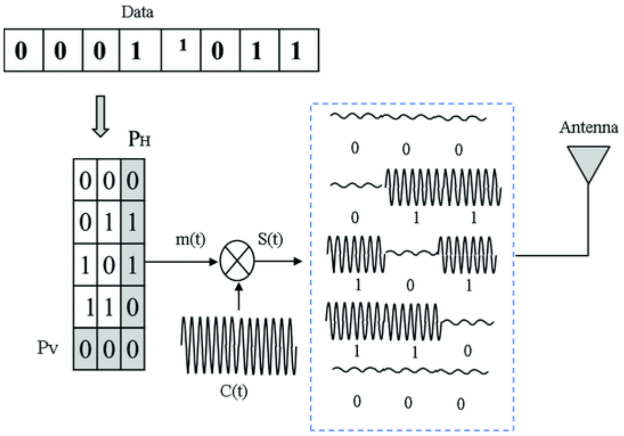


Figure 2.9: Amplitude Shift Keying (ASK). The input is transmitted row by row [20]

- The input signals are the encoded bit sequences being transmitted.
- The Carrier are the radio frequency without modulation.
- The output is the ASK modulated carrier. It consists of two different amplitudes connected to the binary signal. Binary 1, when the amplitude is at its highest means that it`s an on signal and binary 0, when the amplitude is at its lowest means that it`s an off signal.

After the binary data has been transmitted, it needs to be received and demodulated. Because the frequency stays the same through the transmitting, there is only need for one band-pass filter which is tuned to the right frequency considering the carrier frequency. When the signal arrives at the receiver it goes through the band-pass filter and the binary value are decided so that the encoded data block can be recovered.

2.4.3 Phase-shift keying

Phase-shift keying (PSK) is widely used in radio communications as it is well suited to the growing area of data communication. PSK enables data to be carried on a radio communications signal in a more efficient manner than frequency shift keying, which have been mentioned above.

The most basic form of PSK is Binary Phase Shift Keying (BPSK), a digital signal differing between 1 and 0 which create phase reversals.

2.4.4 Direct sequence spread spectrum

Direct sequence spread spectrum is a form of transmission that has a lot of the same characteristics as white noise over bandwidth in a transmission. Nevertheless, when processing the signal with the correct descrambling code, the information needed can be extracted. The way a DSSS signal is transmitted is by multiplying the signal with a spreading/chip code. The method often used when multiplying the signal is XOR (exclusive OR) function. The data has a lower data rate then the resulting data. This is because signals with high data rates uses larger bandwidth than signals with low data rate. After multiplying the signal with the spreading code, the signal is modulated onto a carrier so that the signal is spread over a larger bandwidth [21].

When the signal is received and ready to be transmitted it needs to be demodulated before multiplying the signal with the same spreading code as used earlier. Then only the data generated using the same spreading code is regenerated while the data generated using different spreading codes is neglected [21]. Below there is given an example with 1001 as the data and 0010 as the spreading code. (1x1 = 0 and 1x0 = 1).

1	0	0	1	Data to be transmitted
0010	0010	0010	0010	Chip or spreading code
1101	0010	0010	1101	Resultant spread data output

1101	0010	0010	1101	Incoming CDMA signal
0010	0010	0010	0010	Chip or spreading code
1111	0000	0000	1111	Result of de-spreading
1	0	0	1	Integrated output

Figure 2.10: Example of direct sequence spread spectrum [21].

2.5 Factors that may influence the signal firsthand

Communication using soundwaves has been the primary method used in underwater communication (UWC), mainly due to the non-existent propagation of electromagnetic waves underwater. The principal limitations of the UWC will be covered in this chapter. All these factors determine the temporal and spatial variability of the acoustic channel and make the available bandwidth of the underwater acoustic channel limited on both range and frequency. Short range alternatives, like this particular system is going to be, may have more than a hundred kHz bandwidth [22].

2.5.1 Path loss

Path loss or path attenuation is the reduction in power density of an electromagnetic wave as it propagates through space. Attenuation is the absorption of sound in seawater is the frequency-dependent reduction in sound intensity due to the energy loss. The viscosity of sea water is the main cause of attenuation. Geometric spreading refers to the spreading of sound energy because of continuous expanding of wavefronts. It increases proportionally with the distance and is independent of frequency.

2.5.2 Noise

Ambient noise is related to hydrodynamic movement of the water body. Tides, storm and winds, rain, currents etc. that may act as a disturbance of the communication underwater. Man-made noise is mainly caused by noise from machinery, pumps, engines etc. from either the work boat or other surrounding boats.

2.5.3 Multipath propagation

Multipath is a propagation phenomenon that a signal reaches a receiver by two or more different paths. Transmitted signals may reflect of obstacles or the surface of the ocean. When a device receives both reflected signals and the transmitter in line of sight.

2.5.4 Doppler spread

The Doppler effect is a phenomenon where the frequency of a source signal is shifted when the transmitter is moving towards or away from the receiver, or if the receiver is moving from the transmitter. This effect can be observed if there is relative difference in velocity between the two units.

2.6 Challenges

The characteristics of how the underwater medium treats signals will be the lead limitation factor in achieving the rate of data that is desirable. Firstly, the sound of speed travels faster underwater than on land because of the density makes it easier for it to travel. Even though sound travels faster underwater, about 1500 m/s, it almost does not compare to the speed of light which is 300M m/s. The use of radio frequencies has been restricted for communicating underwater because of attenuation of electromagnetic waves in the underwater medium.

This mentioned, sound travels well underwater due to the density of the particles. Low frequency sounds at about 20 Hz can travel across oceans and ultrasonic frequencies which is 20 kHz ranges in the hundreds of meters. This is the reason that sound waves have been favored in communication underwater.

Although there has been development on the network protocols underwater, the unique characteristics of the behavior of underwater signaling will introduce several problems such as limited bandwidth capacity, delay, and installation.

The main challenges one faces when developing a short-range underwater modem can be summarized in the following categories.

2.6.1 Cost

The most substantial difference between today’s mechanical solution and a potential wireless solution is the cost of a such upgrade. There is increasing interest in creating short-range, low data rate and underwater wireless communication, not only in the seaweed farming business. However, the lack of inexpensive alternatives makes it not as attractive as one would think. This project will in time need hundreds, maybe even thousands of inexpensive, low-power underwater acoustic modems. The problem is not that this have not been invented yet, but the existing commercial modems are too expensive and power consuming to be profitable at this scale. To bring some examples in, Benthos and Linkquest underwater modems both costs more than $8000 dollars [10]. To make our solution even considerable, the price must be driven considerably down. The most critical component when it comes to a cost perspective is usually the transducer.

2.6.2 Placement in the water column

Because today's facilities are usually located in shallow water, the signals have a bigger chance to be scattered or interrupted due to factors that usually appear. This is usually due to tidally stirred waters where sediments from the seabed are stirred up in the water column. This phenomenon makes the water often appears as green to the eye, as seen in Figure 2.11, and can make it more difficult for a signal to reach its destination.

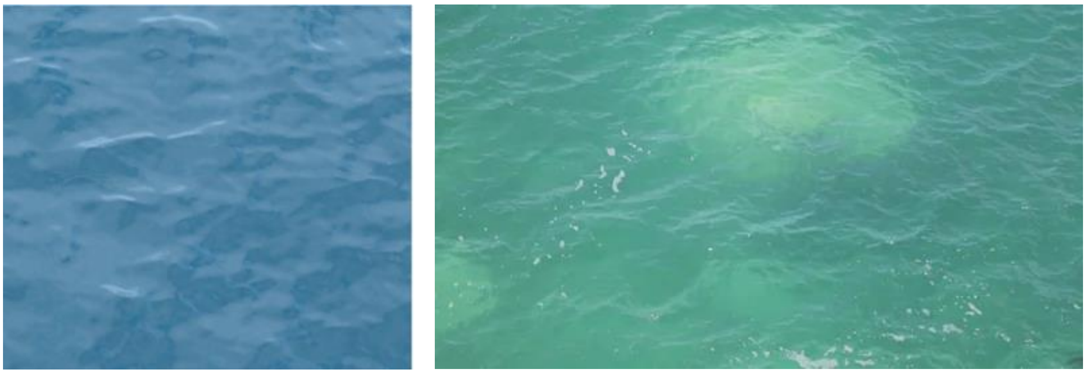


Figure 2.11: Different varieties of ocean water due to differing composition [23], [24]

As previously mentioned, the location of the facilities today can create some problems for the signals that needs to be sent to the clips. As shown in the figure below, fish, the surface and the clips will be 2-4 meters submerged over several months, they are going to be exposed to different threats with regards to organisms and growth. During windy conditions, waves may appear and create disturbance in the water, which can in turn create air bubbles [25].

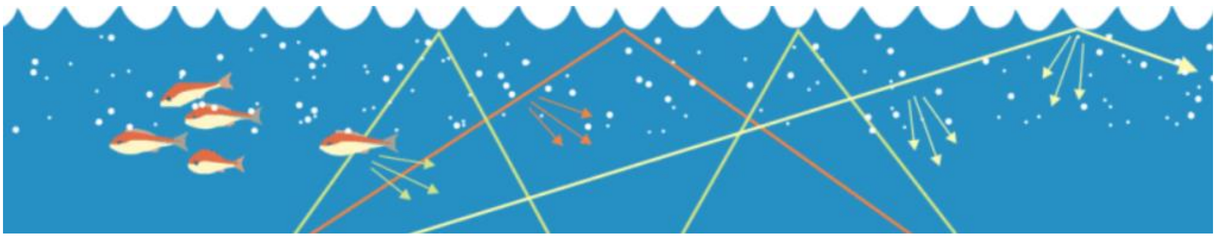


Figure 2.12: Signal scatter in shallow water

2.6.3 Power

Underwater modems cannot be regularly charged if needed. One solution to bypass this problem is by using a low-power wake-up detector. When the modem is idle, it is in a low power sleep mode where only a small part of the modem is on. Even though the modem is idle, it will still need to clamp on around the rope to keep the form of the facility intact. Once the wake-up signal is transmitted and detected by the modem, the circuit will turn on and the necessary function to get the clip to release the growing rope.

2.7 Existing hardware

Underwater Acoustic Communication – UWAC, has become a substantial and highly recognized technology in which many countries, industries and companies are interested in the cutting-edge technology within the UWAC segment. The realise the broad usability of the technology, and how there is an advantage to be updated on it. The technology is controversial among most people and for example a given country's department of defence in which it has just escalated from its humble beginning with Leonardo da Vinci in 1490.

The market was thoroughly examined for commercially available acoustic modems sold by companies across the world. There were identified several companies both in Norway and internationally that provided acoustic modems suitable for this project. However, most of the modems was too expensive and far too advanced for the project. These modems offered many kilometres of range, fast transmission rates and good quality. An explanation to this is that the largest usage of these modems is seen in either military purposes or scientific purposes where they specially are designed to be fitted devices commonly known as acoustic releases. These devices are often used collect and retrieve samples and scientific data on the seabed, depths spanning from a couple 100 meters to full ocean depth. Therefore, these parameters need to be present to achieve the quality and performance to withstand up to several years in sea with high pressure and other threats.

There were discovered several companies in Norway that were providing the relevant technology to this project issue, some of whom was contacted and arranged meetings with to explore possibilities. Among these were Scanmatic AS, Kongsberg Maritime AS and Thelma Biotel AS. Finding that most of the mentioned companies only provided acoustic modems that where overqualified or not suitable for the thesis project, the focus shifted to looking past the land border and overseas for companies that could deliver an acoustic modem that met the criteria for size, but also have sufficient range and other technical properties.

A very interesting company located in Thailand called DSPComm was found intriguing. They provide equipment of high compatibility for Internet of Underwater Things (IoUT) and manufactures acoustic modems and transducers. These contains many features that were great for this thesis project with components like wake-up circuitry which enables for low power usage and a series of different configurations for setting up an underwater internet by a mesh of modems using relay technology. However, sizing and price was still a problem and the hunt for other suppliers were still on. Lastly trough discovering the development of "nano modems" in a project where Newcastle University had been involved, an Italian company called WSENSE was discovered and arranged a meeting with. They had promising equipment regarding both performance and size that will be described more detailed in chapter 4.3.

3. Development

When the wireless communication aspect of the clip has been mapped, the focus shifts towards the mechanical part of the clip. This chapter contains a brief overview of how the system layout is going to be and a development phase from thought and the path into a developed idea. Additionally, a thorough evaluation of the design that the group viewed as the idea with the most potential.

3.1 System layout

The overall layout of the system is shown in Figure 3.1. The system consists of two areas of operation and therefore two different types of units, the user surface unit, and the clip unit. The surface unit can be located anywhere in range of the clip unit. However, it is most advantageous to be operated at the vessel used for harvesting at the surface and in near proximity of the production site. The clip units are submerged a couple of meters deep and are spread evenly across the site. The personnel at the harvesting vessel will utilize the surface unit which enables them to communicate with the desired clip unit trough a user interface.

The system utilizes and consists of acoustic modem technology, which is described in chapter 2.2.1, for communicating over impressive distances in seawater. The units are developed to house some of the same components, but not all the components are the same in both the surface unit and the clip unit since they are assigned different sender/receiver tasks. The surface unit is responsible for interacting with the operators, connect, send, and receive data to and from the clip units. On the other side of the communication channel, there is the clip units which have many of the same requirements as the surface unit, but most importantly it needs to be able to detach itself from the kelp/seaweed production/growth rope.

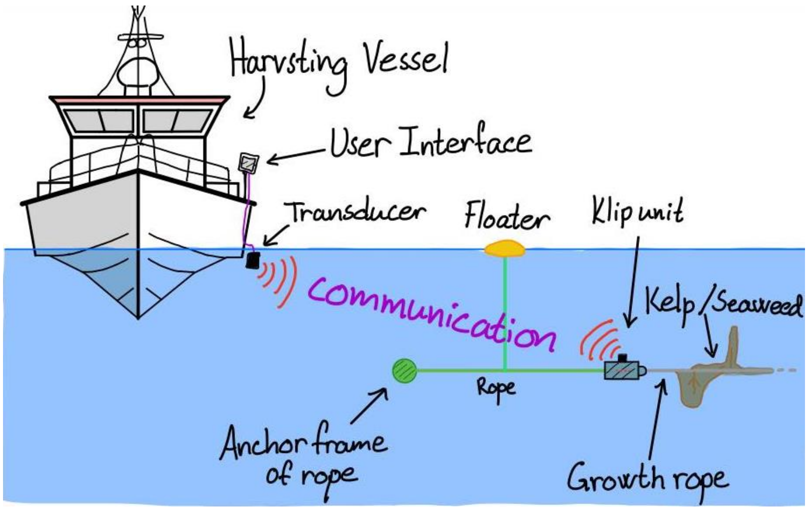


Figure 3.1: System Layout

As seen in Figure 3.1, is how the ideal process is going to play out in a harvesting situation. The harvesting vessel will maneuver to one of the ends of the facility to grab a hold of the growing rope and systematically release the desired clips.

3.2 User interface

The user interface is considered as just as important as the rest of the system because it is how the operators are going to access the several hundreds of clips that are located within the facility. Because the number of clips is so many, a map of the clips is made when the rope is being deployed. This makes it easier for the user to choose which of the clips he wants to open. When the address for the clip the user wants to open is inserted, a red circle will appear around the chosen clip. If this is the correct clip, the user pushes the green button so that the clip releases the rope. A similar process for deploying and creating the grid size for the plant is shown in Figure 3.2.

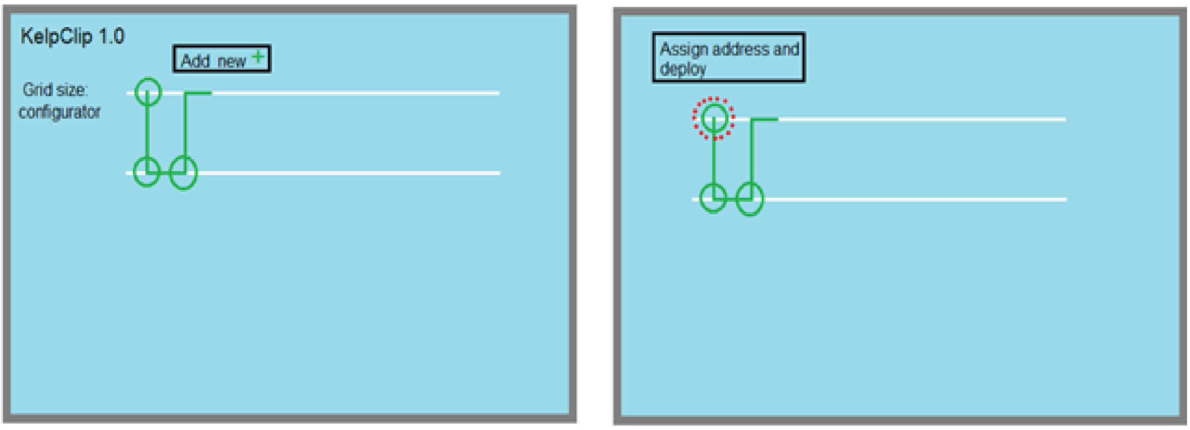


Figure 3.2: Concept idea of the user interface

3.3 Surface unit

The surface unit will consist with the UI mentioned in the previous sub-chapter and listed in the table below are the wishes and demands presented from the contracting company on how a surface unit needs to be.

Demand/Wish	Requirements
D	User-friendly
D	Water resistant
D	Easy to set up
W	Compact

Table 3.1: Requirement list for the surface unit

The surface unit is working as one unit but could be described as two units. One unit is the tablet in which the user interface is installed. The rest of the surface unit is a box with modem, transducer, optional batteries etc. The surface unit receives a binary code from the user interface and demodulated the signal before sending it to the chosen clip.

3.4 Clip unit

Being the most crucial part of the system, the clip must be as reliable as possible. Therefore, the clip contains a detailed list of demands and wishes that needs to be fulfilled to secure a safe operation as possible.

Demand/Wish	Clip requirements
D	Must grip around the rope tightly
D	Must be waterproof
D	Have sufficient mechanical strength
W	Low mechanical complexity
W	Have a manual release for redundancy
W	Easily be tightened by hand at deployment.
D	Compact
D	Durable
D	Keep tangling of ropes at a minimum
D	Reliable
W	Have positive buoyancy.
D	Low cost
D	Easy manufacturing
D	Withstand corrosion
D	Be independent of attachment in the growing rope
W	Have few intersections between housing and outer mechanism
D	Feasibility
D	Release one clip at a time
W	Able to reach clips within a range of 100m
D	Enough power to last the growing season

Table 3.2: Requirement list for the clip unit

The clip unit has two important aspects which is intertwined but can also be looked at separately. Those are the electrical aspect of the clip and the mechanical aspect. This thesis is mostly focusing on developing the mechanical solution for the clip unit. However, it should be noted that the mechanical solution is developed with the electrical aspect in mind and with the end goal to that both electrical and mechanical solution is combined to make one unit.

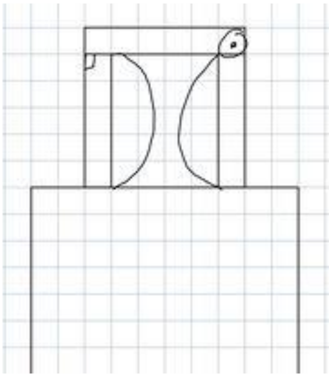
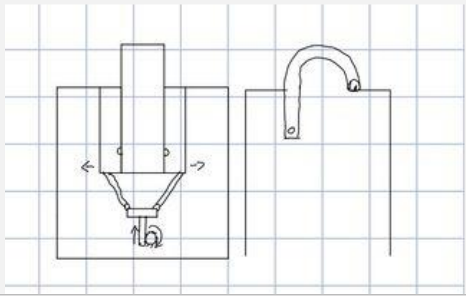
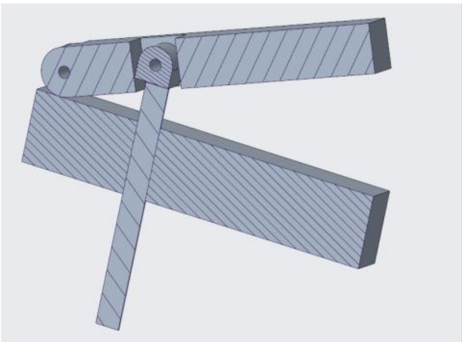
The electrical solution consists of parts that is fulfilling two important tasks. The communication between surface unit and clip unit and actuating the release of the mechanism. The communication is taken care of an acoustic modem which is powered by its own source of electricity. Connected to the modem is a transducer which is part of the physical layer according to the OSI model. The transducer is converting the electrical signal to sound waves that propagates trough the sea and the other way around by converting sound waves to electrical signals. The modem also has outputs that can send signals to the actuation circuit which is also powered by its own local source of electricity.

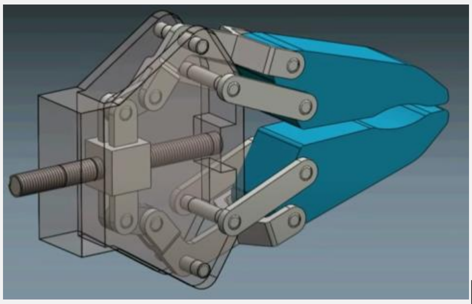
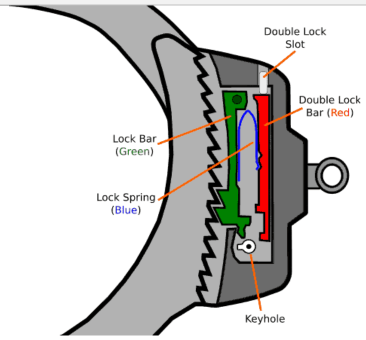
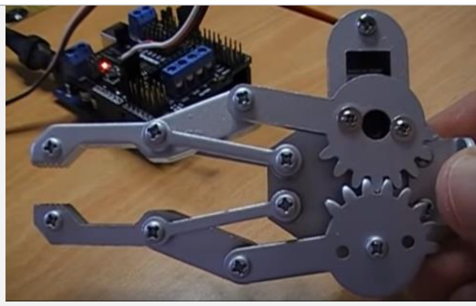
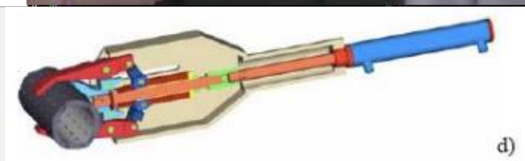
3.4.1 Mechanical development

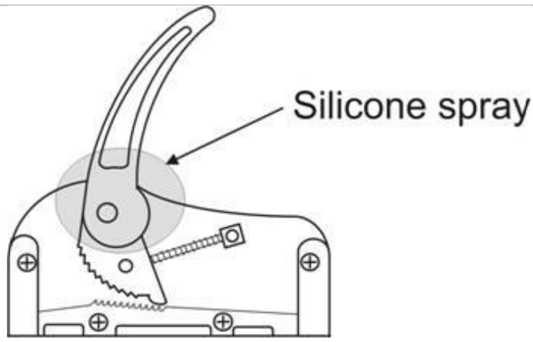
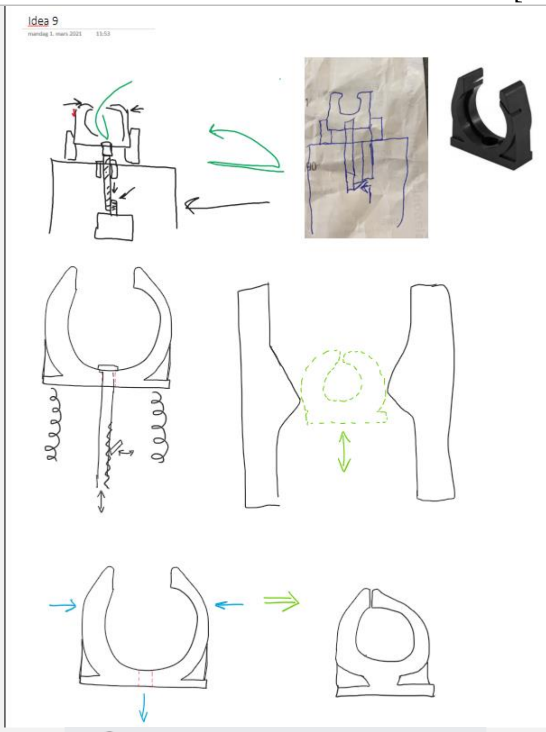
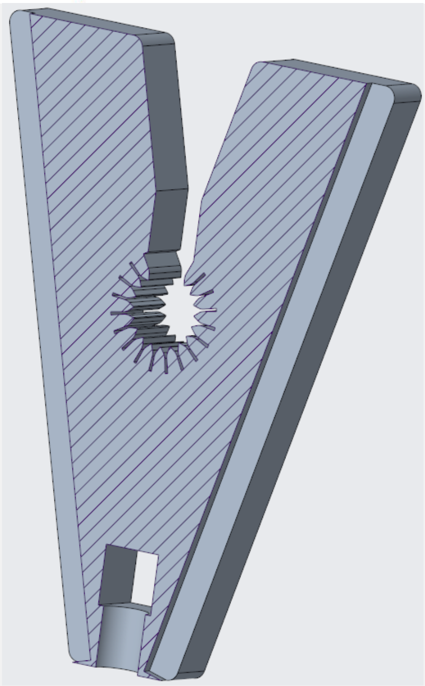
It was decided that to solve the issue of designing a mechanism that fit the demands and wishes, the implementation of a protocol system would highlight key parameters and properties. The method chosen is to first perform a brainstorming session where creativity and inspiration is key for solving the issue at hand. All ideas are listed and described in a table below. Following the brainstorming, a spreadsheet containing the criteria together with the respective ideas was to be made. Each idea will then receive scores ranging from 0 to 10 based on different criteria. The spreadsheet outputs a total score for each idea which is useful for the group to assess and rank the best ideas. The best ideas will undergo a further analysis where there will be another round of filtering to go further into detail with and eventually decide on the best idea. The idea that the group thinks is best will go into an engineering phase described in Chapter 4.

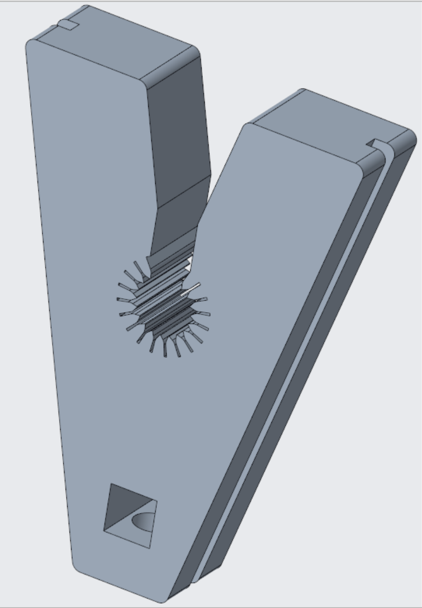
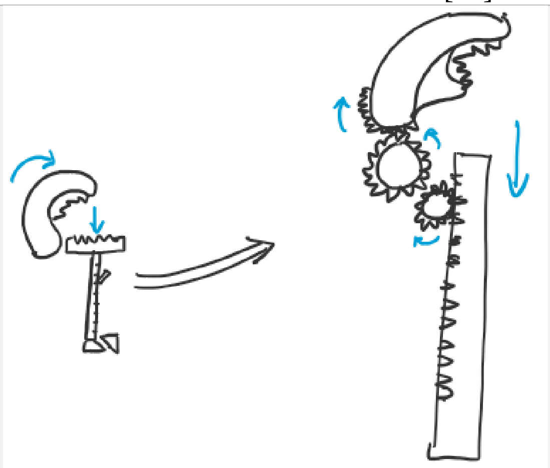
Idea brainstorming / List of ideas

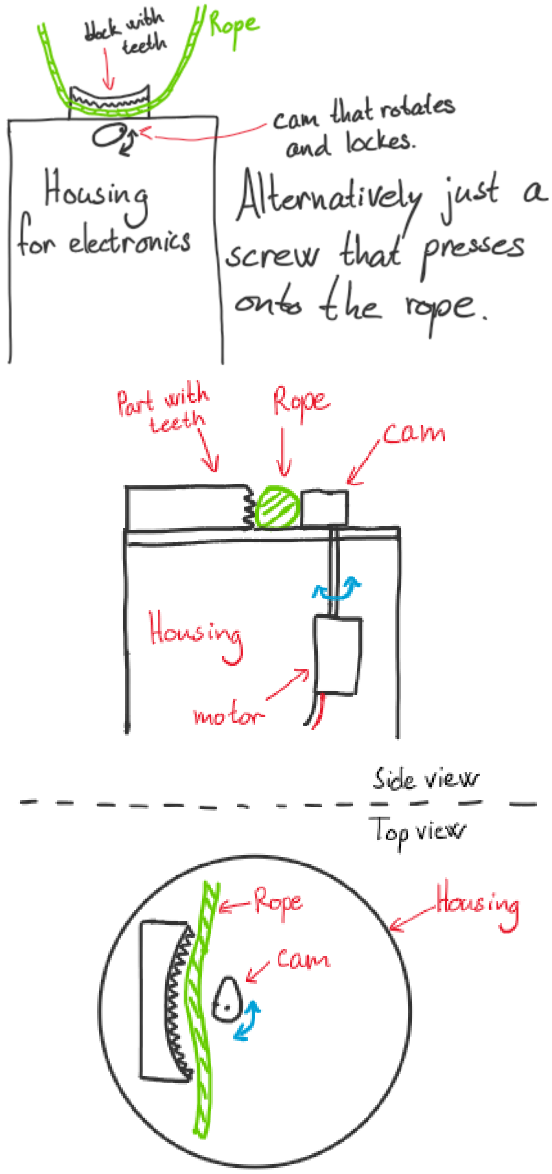
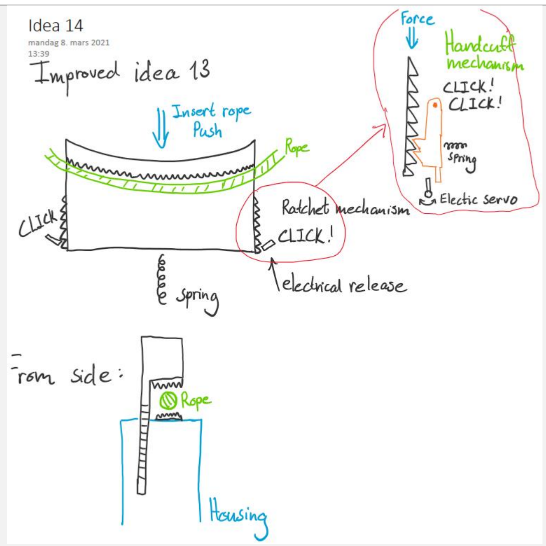
Idea	Description	Illustration
Dishwasher tablet clip	Conserves the form of the clip, but the material is degradable from the moment it is submerged in the water. Over time it gets weaker and weaker until it is time for harvesting the seaweed. The clip has then weakened enough that the harvester can just yank the growing rope and the clip releases itself.	
ROV	A ROV is going to be used to unclip each of the wanted clip in the desired order. This makes it possible for the crew on the working boat to sit completely dry while the ROV does the work with releasing each of the growing rope. You would also have full control of which clip you are opening, unlike the dishwasher clip where you might have to harvest in an already chosen order.	 [26]

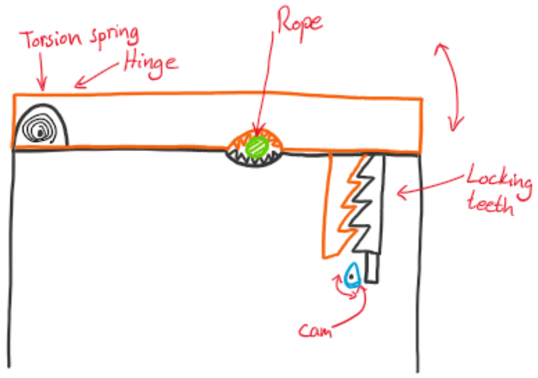
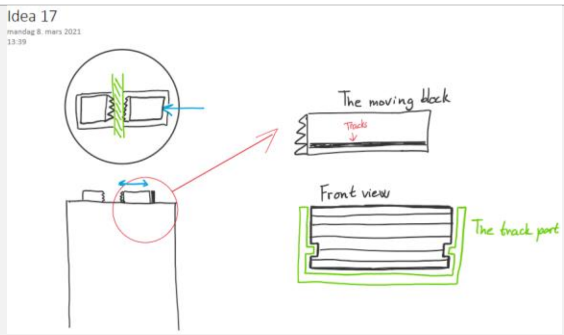
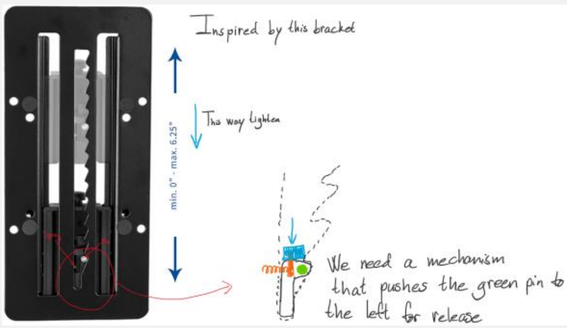
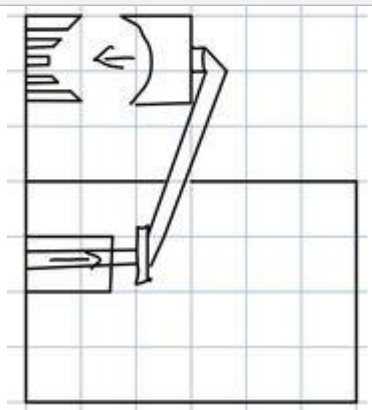
Idea	Description	Illustration
Robot hand	A robotic hand which tightly grabs the robot when in close position and opens fully when it releases the rope.	 [27]
Air pillow	When in closed position the pillows will be filled with air until the rope sits tight enough. When in opened position the air slips out of the pillows, and the rope is loose. The stick-on top is for keeping the rope in place until they are ready to fill the pillows with air. The lock is pressure sensitive and will open quite easily when the start pulling the rope.	
The eel-catching method	When fastening the rope, they press the hook down between two pillars until it clicks in place. It opens when a signal is given to start the motor that pushes the plate upwards until the hook pops open and the rope is free.	
Simple clamp with threaded shaft.	Idea is to clamp the rope between the two main pieces which is applied pressure to by a shaft with threads. An electrical motor would apply the rotation for the threaded shaft.	

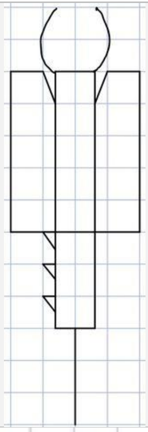
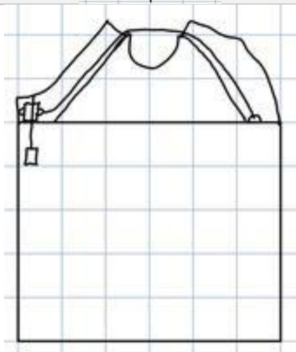
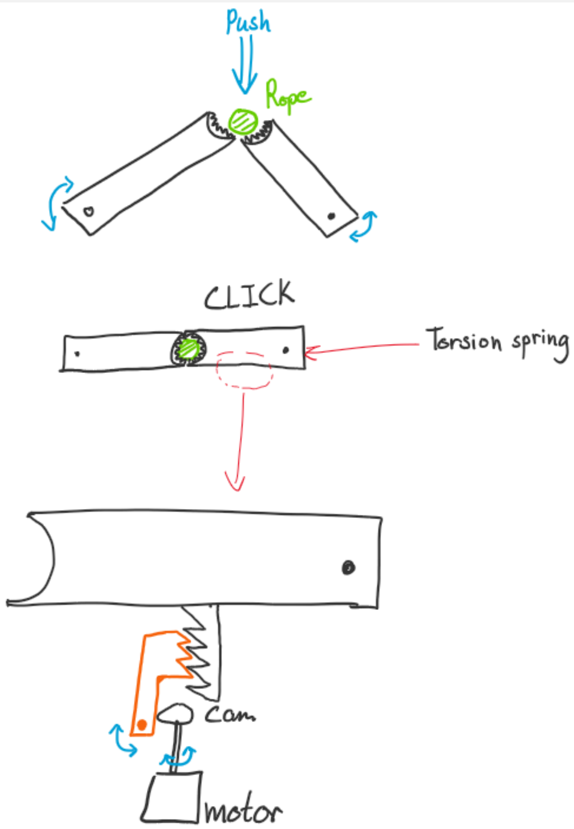
Idea	Description	Illustration
Mechanical claw.	Mechanical claw actuated by rotating shaft with threads.	 [28]
Martin's handcuffs.	Using Martin's handcuffs as inspiration for having a ratchet mechanism for tightening and locking the rope in place.	 [29]
Claw	Another form of mechanism, but with rotating gears instead of threaded shaft.	 [30]
Compliant mechanisms.	Reducing cost and moving parts/joints will enable higher reliability.	
Claw 2	A bit complicated claw.	 d) [31]

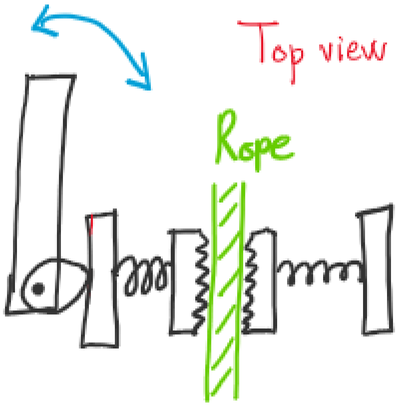
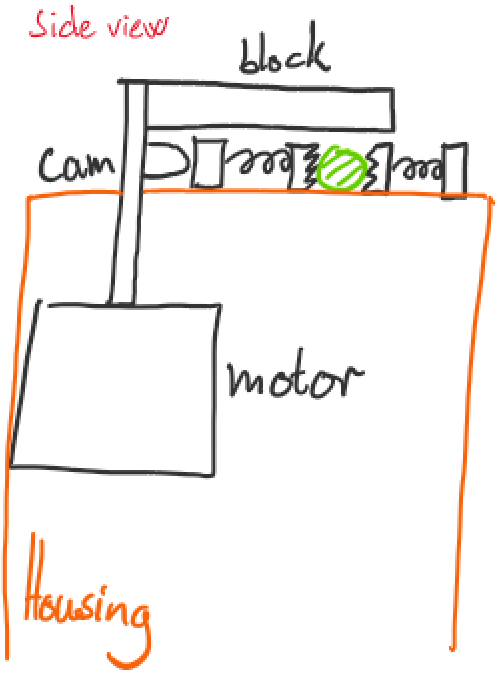
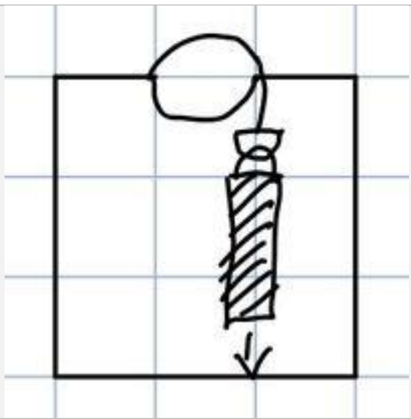
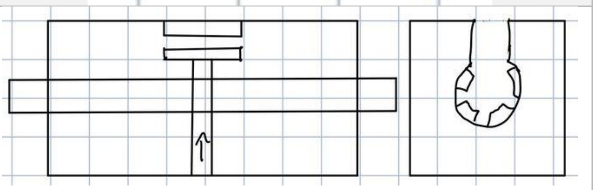
Idea	Description	Illustration
Rope clutch	Put it sideways on top of the housing.	 [32]
Plastic clamp.	Plastic insert that clamps and locks when it is pulled down. Inspired by plastic pipe clamps.	 

Idea	Description	Illustration
		
Linear actuator	Mechanism that could be used for detaching.	 [33]
Claws with gears.	A design that consists of claws that grips around a rope when the rope is pressing down on a plate which turns a set of gears that is connected to the claws. Has a rachet locking mechanism.	

Idea	Description	Illustration
The cam axle/screw idea	A piece with teeth that the rope loop can fit into. A cam that is rotated will apply pressure on it. Could alternatively just be a screw that applies the pressure.	
Track clamp	Another piece of material with teeth that the rope loop can fit into. Has ratchet mechanism on either side and is spring loaded in the bottom. Electric servo that releases the pressure.	

Idea	**Description**	**Illustration**
Bridge clamp	A hinged mechanism with ratchet mechanism.	
Bracket-clip	A mechanism inspired by a bracket for adjusting hight of a PC-monitor. It consists of a plate with tracks that a carriage can fit into and slide with small increments till it reaches the end, then it must be slid back to start to be able to start with the increments again. The idea is to make something similar where to pieces squeezes the rope. One of the pieces is part of a carriage that is tightened incrementally towards the other piece. When time comes for releasing, the pin which travels in the incremental notches gets disconnected and the carriage shoots back with spring force.	
Nozzle clip	A lever which pushes on the plate so that the clamps grips around the rope	

Idea	Description	Illustration
The kayak clip	A clamp that grips harder on the ropes the heavier the rope gets. Turn the lever 90 degrees to release the rope.	
Rubber band clamp	A rubber band that you tighten over the rope by pulling the brick which the rubber band is fasten too, and then a lever goes through the brick when it`s in the right place	
Jointed clip	Two pieces of a material is made to have semicircle in one end. The other end is hinged and have torsion springs that applies a tension that wants to open the clip. On the each of the pieces there is a ratchet looking mechanism that is also spring loaded. When the clip is going to detach the rope, the ratchet mechanism gets disconnected by a cam that pushes the teeth away from each other. The rope is tightly squeezed between the two pieces making a complete circle for the rope to be trapped in.	

Idea	**Description**	**Illustration**
The spring clip	Two pieces of a material is made to have teeth that squeezes the rope. They are squeezing on the rope with spring force from each side. On one of the sides the spring is connected to another part that can adjust the spring force by rotating a cam. On the same axle as the cam, there is a part that blocks the rope in upwards direction when in locked position.	 
Waist clip	Fasten a rubber band in a bolt that screws down until the rope is secured	
The box	Some sort of a box that you put the ropes in and when you close the lid, teeth grips around the rope. When releasing, a lever will push open the lid and the rope is free.	

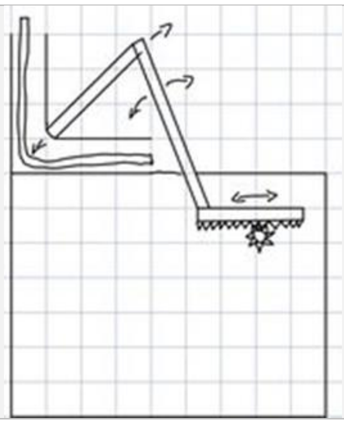
Idea	Description	Illustration
Gripping excavator		

Table 3.3: Idea overview

3.4.2 Idea evaluation parameters

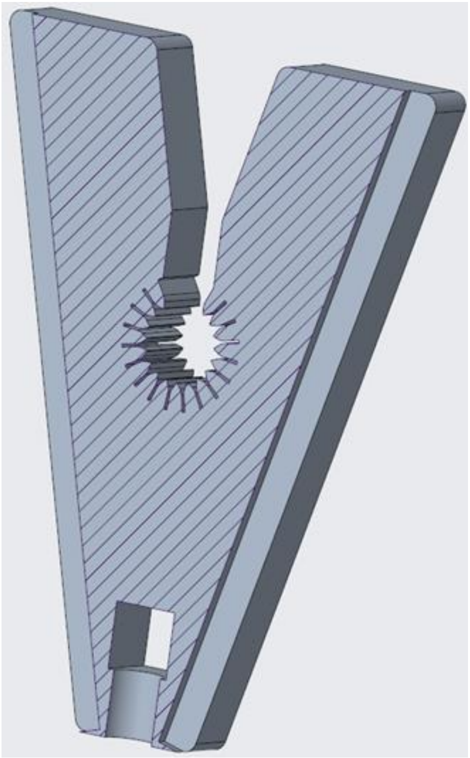
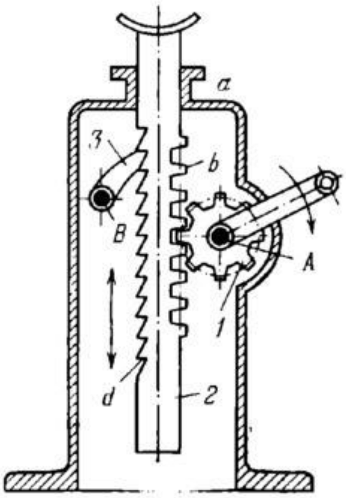
These are the mechanical parameters in which the ideas for the mechanism are evaluated after.

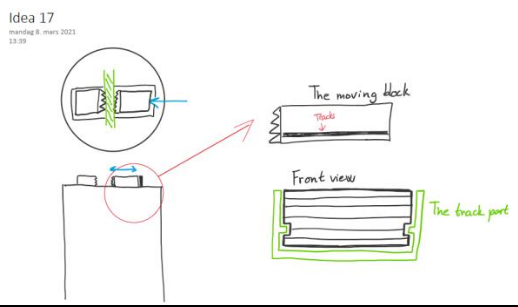
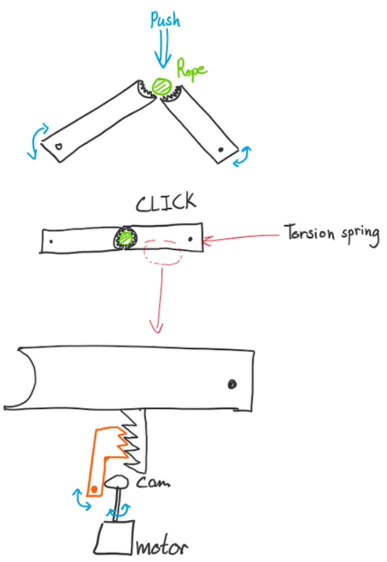
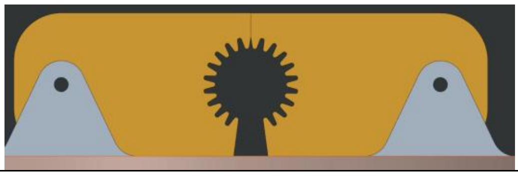
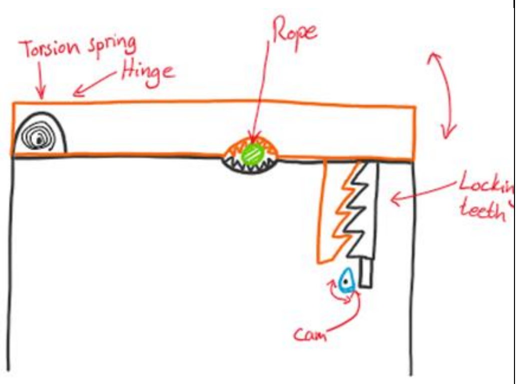
Importance (%)	Parameters
100	Must grip around the rope tightly
100	Must be waterproof
100	Have sufficient mechanical strength
70	Low mechanical complexity
65	Have a manual release for redundancy
80	Easily be tightened by hand at deployment.
55	Compact
90	Durable
100	Keep tangling of ropes at a minimum
100	Reliable
80	Low cost.
60	Easy manufacturing.
100	Withstand corrosion.
80	Feasibility

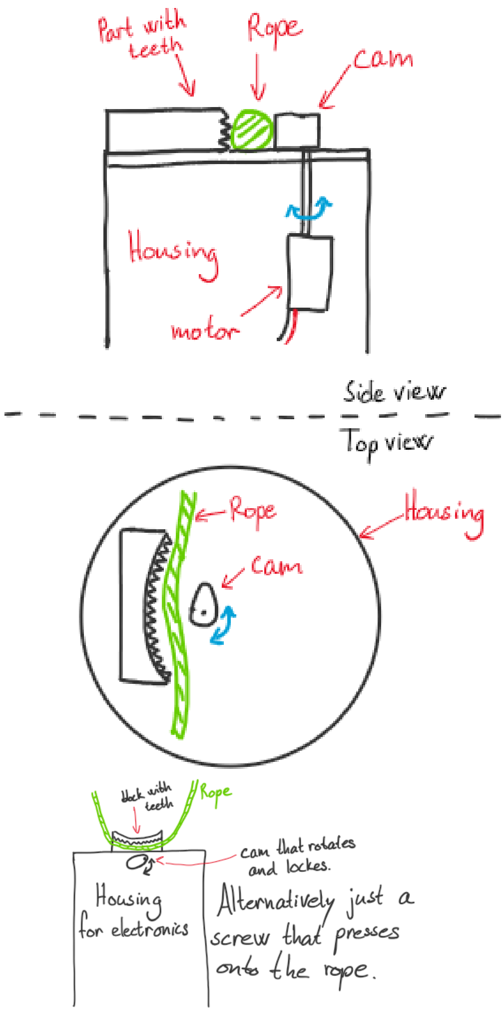
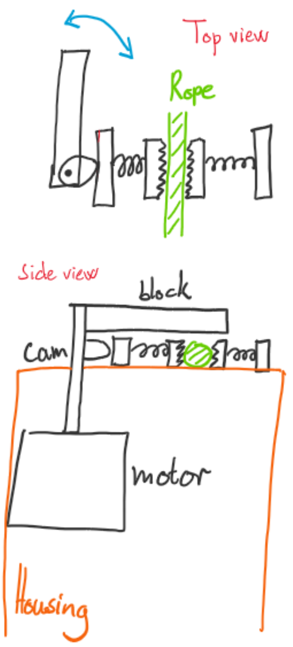
Table 3.4: Idea evaluation parameters

3.4.3 Evaluation of ideas

These are the ideas that got the highest rating and is presented more detailed with a list of weaknesses and how to strengthen those weaknesses.

Idea	Picture	Weaknesses	Fix
Idea 13, Plastic clamp	 	1. Lack of redundancy. 2. Hand tightening. 3. Mechanically advanced. 4. Forces acting directly on locking teeth.	1. Simplify by making the clamp out of two hinged parts.

Idea 19, Bracket clip		1. Mechanical complex. 2. No overhang to secure rope. 3. Lack of redundancy.	1. Attach “lip” to the moving part.
Idea 23, Jointed clip	 	1. Redundancy. 2. Waterproofing.	
Idea 18, Bridge clamp		1. More risk of tangling. 2. Redundancy. 3. Waterproofing.	1. Add gasket to reduce contact surface. 2. Move the locking teeth to the other side of the rope. 3. Make a housing for the locking teeth.

Idea 16, Cam axle		1. No overhang to secure rope. 2. Low strength? 3. Redundancy 4. Electrical motor needs to be powerful. 5. No locking without gearing or applying voltage to motor.	1. Attach "lip" to cam axle 2. Reduce length between motor and cam axle 3. Make the part with teeth is removeable.
Idea 24, Spring clip		1. Redundancy. 2. The swingarm is a bit loose.	

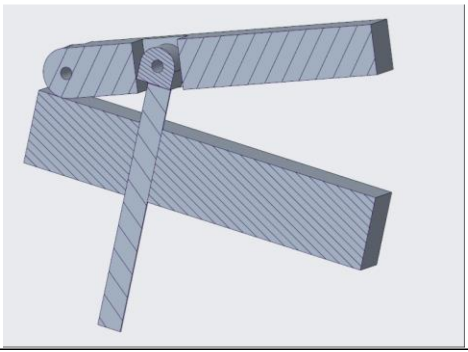
Idea 6, Simple clamp		1. Tangling 2. Low strength	1. Make the parts shorter or rounder to make the ropes slip past instead of hooking 2. Move the pin closer to the gap to get more moment

Table 3.5: Idea evaluation

The idea that the group settled with as the best idea was idea 13, plastic clamp. This idea scored high in the initial evaluation and was fundamentally preferred by the group. There are however some weaknesses that appeared when the best ideas from the initial evaluation was further investigated. For example, how the forces would be concentrated on the locking mechanism, and therefore it would need a lot of power to open the lock. Also, the opening of the clamp would be in the direction of which the forces from the rope would be acting. Making the need for a lot more gripping power then if the forces from the rope were acting on the housing of the clip instead.

3.4.4 Evolution of idea

The first step was to go more into detail with "Idea 13", shown in Figure 3.3. The group made some changes to the initial idea whilst also implementing a method for locking it in place, tightly, with room for different sizes of rope. The idea was to have two clamps hinged to a common part that had a rod attached to it. When the common part was translated vertically, the clamps would follow the contours of two walls that they were attached to. The rod that attaches to the common part would have a set of teeth cut into it. Those teeth would be meant to work as a ratchet mechanism by allowing movement only in the down direction making the clamps grasping tighter around the rope. The ratchet mechanism itself was to consist of two opposing parts with teeth that was spring loaded and could be moved away by moving two leverage arms with a DC motor. However, this design proved to be advanced by having many parts and properties which made the group having to think outside of the box.

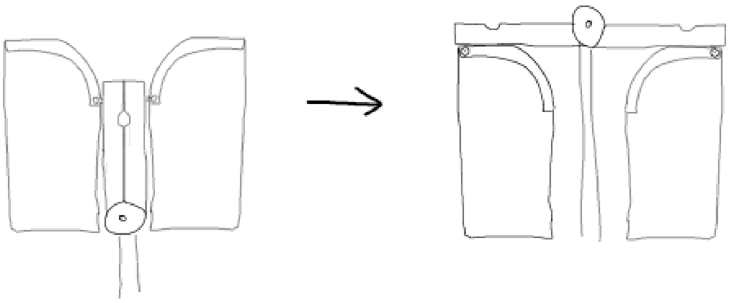
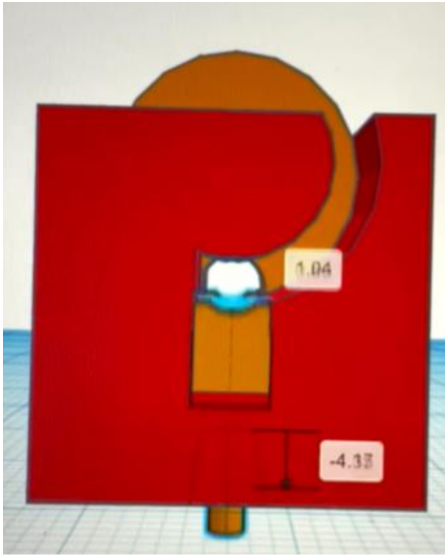


Figure 3.3: Early concept of "Idea 13"

The common denominator amongst the best ideas was the direction of force. The load of the fully grown seaweed would have added tension making it harder for the release system to function properly. A new solution which worked around the forces being focused on the closing mechanism, and instead on something independent of the release mechanism was the chosen way to go. A completely new concept with a new design, with the new knowledge learned from the initial "Idea 13" was made in the form of a wheel.



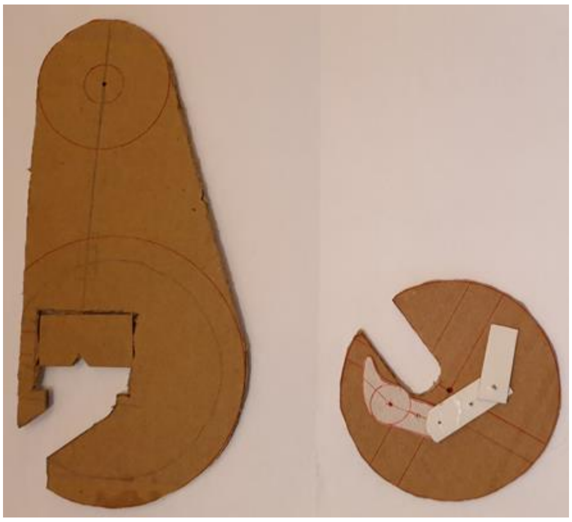


Figure 3.4: The first draft of the wheel *Figure 3.5: Early cardboard construction of the clip*

The proposed solution contains a shift of the force load away from the closing mechanism. As seen in Figure 3.4, a wheel was introduced to the idea as a step to direct the forces away from the mechanism that squeezes the rope as well as having the properties to rotate the rope out upon release. This would reduce the power needed for retracting the closing mechanism and lead the forces from the heavy seaweed towards solid material instead.

The wheel idea was the idea that led up to become the final type of idea. Although somewhat altered, the final idea is based on using a wheel to rotate the ropes position so that the forces act in a different direction and does not impact the locking mechanism. The concept is to build up the clip by layers of material and is shown in an early state in Figure 3.5. In one end of the clip there is a hole for attaching a shackle that connects the clip to the anchoring frame.

In the other end of the clip there is a slight opening for a rope to get inserted. By inserting a rope, it would follow a channel that is cut out in a wheel. The channel does not go straight into the center of the wheel but is shifted slightly to the side from center which makes a small leverage arm from the center to the small pit where the channel ends. By rotating the wheel after inserting a rope, the rope will be squeezed tightly by a small spring-loaded bar with a triangular notch cut out of it. This will stop the rope from sliding inside the clip and the triangular shape allows for different dimensions of rope to be clamped. When the wheel is rotated so that the forces are all aligned to one imaginary line between the shackle hole and the rope position, two holes drilled out in both the wheel casing and the wheel itself will be aligned.

A pin that fits these two holes will lock the wheel in closed position. This pin can be actuated by a solenoid or a small mechanism driven by a DC motor. The idea is that most of the forces from pulling the rope would be absorbed by the wheel casing and not be translated as large lateral forces acting on the pin. This would make the efforts for shifting the pin up and down low and possible by compact and small electrical equipment. The clip is designed with no parts sticking out so that the chance of tangling is kept at minimum. A nod is connected to the wheel so that the user easily can turn the wheel to its locking position. The nod is even with the outmost plate for preventing any tangling. Inside the clip there will be a room for electronics to be stored and this room is sealed tight by tightening all layers of material with bolts and gaskets.

4. Engineering

From this point and going forward, the cardboard construction idea was chosen to continue working on together with the wheel concept as this was considered the best base to build onto. With this idea in mind, the strengths and key parameters from other selected ideas were also added with coming up with the best possible solution in mind.

In this chapter a more detailed explanation of the design and its development is presented. It will address how the decisions regarding the parameters of the design and how those changed through extensive 3D modeling and 3D printing. Two iterations of the design process resulted in two 3D-printed prototypes where the final iteration is a close representation of what the final product is thought to be. By being able timewise to produce two 3D-prints of the design in this engineering phase, the outcome was greatly increased since the perception of the design was changed by being physically able to see and inspect the printed model. This chapter will capture the thoughts and ideas in the process to address how the design was enhanced.

4.1 First iteration of the design and 3D-printed prototype model

Construction / Assembly / Composition

The construction and total assembly of the clip consists of five layers in which could be easily manufactured from plates of desired material. These layers are assembled in a stack and is the source of the mechanical strength and is held tightly together by several thoroughgoing bolts. Together these layers form the clip itself in shape and acts as a casing and encapsulation for the components located inside.

The main properties of the composition of layers all together is to act as the structural integrity of the clip so that it can hold parts together, absorb the forces applied to it by the weight of the growing seaweed and keeping the electronics dry and sealed away from the water. The layers from the outside and in consists of two for sealing purposes, two for holding the wheels in their tracks and lock the wheels and finally in the middle, a layer with the spring-loaded clamp.

A key part of this design is that it is designed for a very specific task which implies that for the clip to work as intended the boundary- and framework conditions for using it should be correct. One such important framework condition is that the mounting solution in the shackle hole is allowing enough rotational freedom. This will, together with the clip being very short in length in comparison to what it is used for, make sure that the forces are acting in the general direction that the clip is designed for.

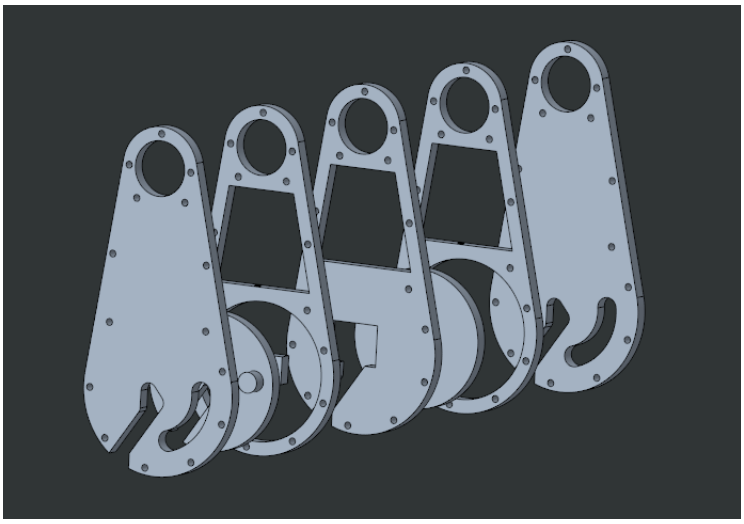


Figure 4.1: Exploded view of the clip

Main layer of action

The main layer of action consists of a wheel with a special design, a housing that the wheel fits into and a locking pin mechanism. This is the first layer to be designed, starting with the wheel itself. The layer is responsible for the core mechanism of the clip: translating the rope loop to a secure position and locking it in place. The overall concept is clearly visible in this layer.

A shackle hole located in the top of the layer, the locking pin, and the rope resting position in the wheel is designed to be in the same vertical line, located slightly of center to the wheel to make a small moment arm from the center. By inserting the locking pin through a hole in both the housing and the wheel, they will interlock each other. The purpose of having all these key features in the same invisible vertical line as shown in figure 4.2 is to minimize the forces acting on the locking pin. It assures that the applied pressure from the rope will act in this vertical line. The wheel is designed with a track running from the outside and in with the same width as diameter of the largest compatible rope. The track ends with a circular shape that is located with a set offset from center. The wheel has a shaft cut into it for the locking pin running across the width of the wheel and trough the offset line. Some type of seal is to be implemented to prevent water from coming up this shaft and into the electronics, similarly to a hydraulic piston.

There is also a small knob added to one side of the wheel which is to be accessed from the outside by an operator to rotate the wheel by hand when deploying the clip. The housing is designed to be smooth on the inside of the circular shape so that the wheel can run freely in there with some lubrication. The tolerance between wheel and housing is set to be adequately small. In the housing there is also made room for the electronics which were unknown at the time of this first initial design, so the cavity was made reasonably large. The initial width of the layer was set to be 15mm.

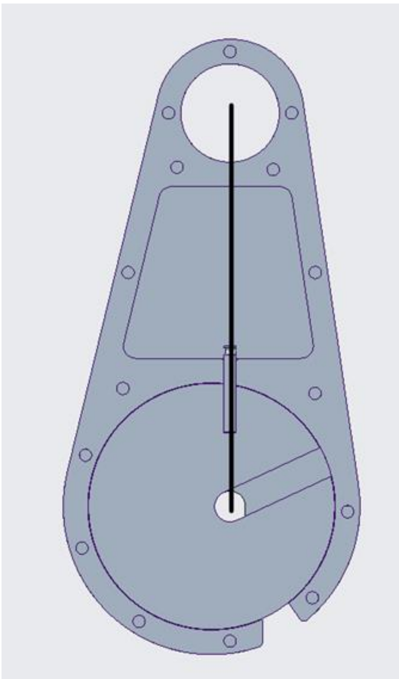


Figure 4.2: Spring loaded tightening mechanism

Clamping layer

One of the requirements/wishes that were assigned from Lerøy/Ocean Forest was the possibility to vary between different rope thicknesses. The diameter of the rope could vary between 6-20 mm, depending on the surrounding conditions. To make this possible, a solution to make the clip universal regardless of the diameter was added. The solution was to integrate a vertically displaceable clamping element that ensures a constant pressure on the rope with a shape that is compatible with different rope sizes from 6-20 mm.

To ensure a safe and secure fastening of the rope, the preservation of the clamping force of the original clip used today, which was measured to be around 8 kg, would also be present in the new concept clip. The clamping force is provided from a spring that is located in a shaft between the clamping element and the wall separating the clamp from the electronics which also constitutes as a structural member of the clip.

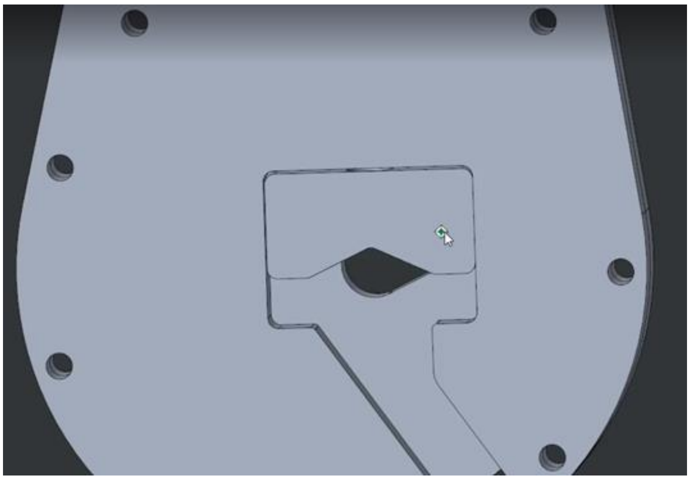


Figure 4.3: Spring loaded tightening mechanism

Outer layers

The outer layer located on each side of the clip has the main property to seal and protect the clip against water and other potential destructive floating debris. The initial design of the layer was only to match the other layers in shape and design, but only having cutouts for the knob on the wheel and the ropes path. Another important feature that was added to the design of these plates was to round all sharp edges that could introduce chafing on ropes. This layer is planned to be substantially thinner than the two other layers, but it will still add tensile strength to the clip together with the thoroughgoing bolts.

3D-printing the first prototype

To make the first prototype print more efficient, two of the middle plates were merged into one, the wheel layer and clamping layer. The collective mechanical strength was also increased in this print because of the composition of the merged plates/layers. The main goal of the first 3D print was to ensure that the mechanism of the wheel was functional. At the time, there were not acquired a correctly suited spring and used a smaller and less strong one only for testing purposes. By performing an initial dry test, as seen in picture 4.4, with the clip suspended vertically and a 4 kg weight attached it is possible to see that the mechanism was indeed working as designed.

Figure 4.4: Testing release mechanism with 4kg load   *Figure 4.5: First 3D prototype*

The knowledge extracted from the 3D printed prototype was considered very valuable. It was assessed that the spring tightening did not offer enough strength with the small spring as thought, and nor was there enough displacement room for the clamping element to do what it was implemented to do. A proposed solution was to make a compartment to fit a larger and more heavy-duty spring which provides the correct clamping force as well as making sure that the range of motion of the clamping element was sufficient.

Another potential problem, or rather area with potential for improvement, was that the size of the wheel itself was bigger than it needed to be with a diameter of 100 mm. With a downsize of the wheel, the possibility of increasing the thickness of the arms, which was a potential liability, holding it in place will present itself. Finally, the group evaluated that the general shape and some design points of the clip could be altered to make it a more efficient design with more space for electronics.

When the 3D printed version was inspected, the size was the part that surprised the group the most. As seen in Figure 4.4, with a pen for scale, the clip was considered somewhat over-dimensioned. This provided a foundation on how a second iteration could be made more space efficient.

4.2 Second and final iteration of the design and prototype

A second and final iteration of the design was made to improve the faults and drawbacks from the first iteration. Although the general design and idea stayed the same, most of the components was altered in some way or another. The design of the new clip is shown in figure 4.6.

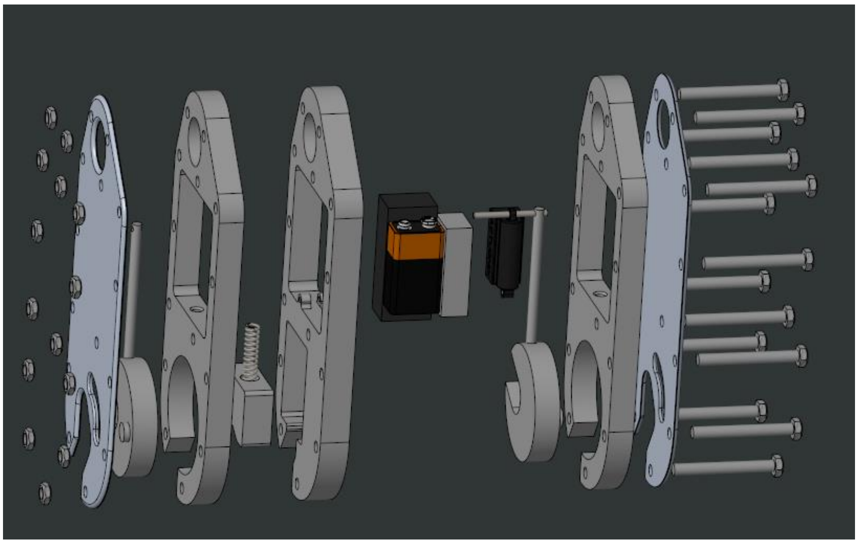


Figure 4.6: Overview of the clip with electronics

Changes made to the design

The main visible changes made was to make the clip overall smaller, starting with reducing the size of the wheel. The wheel was designed this time with a smaller outside diameter of 60 mm instead of the previous 100 mm, other than adding a small chamfer on the edge of the pin shaft to guide the pin more easily, it retains the features from the first iteration.

After improving the design of the wheel, the overall shape of the clip was altered to make a more practical room for the electronics. Starting with increasing the wall thickness in the wheel housing around the wheel from 10 mm to 15 mm for more strength and from there drawing two vertical lines from each opposite radius. The lines continue to where they meet given height that is given by knowing how much room that is needed for the electronics which are mentioned in chapter 4.3.

At this point the lines changes direction inwards towards the shackle hole and its outer diameter, which also is increased for strength purposes, where they are tangent. The shape of the clip overall is now formed more rectangular like on the middle with the sides being parallel to each other. The overall length of the clip is also reduced from 250.5 mm to 214 mm, the width from120.5 mm to 90 mm and the depth from 55 mm to 46 mm between outer plates. The layer thicknesses are reduced from 15 mm down to 13 mm for the wheel layer, the outer plates are reduced to 2,5 mm and the clamping layer stays the same.

The clamping layer and the clamping element was also altered to fit a stronger spring. The group acquired three springs with different properties that can be interchanged for testing purposes. The shaft for holding the spring in place was made deeper into the material of both the clamping layer and the clamping element, making it impossible for the spring to dislocate itself. The clamping element was altered to be a bit larger in the process, but it retains the general shape as from the last iteration.

Finally, the outer layer has not been changed in any significant way other than being plasma cut out of 2,5 mm aluminum plate for this prototype. A short review of the material choices can be read about in Chapter 4.4.

4.3 Electronics

The group decided, after researching the existing available technology and talking to several providers of UWAC-equipment that the acoustic modems from the Italian company WSENSE would be suitable. Most importantly for this project is the size, cost and power consumption of the electronics since the clip must be compact and self-sufficient with electricity. The size needs to be small enough to be fitted inside the clip along with other components such as batteries, actuator and release mechanism, wires and other circuit boards if necessary. WSENSE is a company that specializes in monitoring and communication systems with their pioneering patented solutions in the Internet of Underwater Things (IoUT) [34]. A development of relatively affordable and small “nano modems” as well as even smaller “pico modems” has shown to be useful for this occasion as one such nano modem meets the criteria that the group has found and set to be required.

Knowing that very long range and high bandwidth is not necessary in this project, the acoustic modem offered by WSENSE is chosen for this project. Their modem has the impressive small size of cylinder with approximately 10 mm diameter and 50mm length which is well within the groups criteria. Their modem also has around 500 meter of range and operates on 3 volts supplied from included batteries. It also has the options for having the transducer directly mounted on it or located externally with a wire. The modem transmits and receives with a data rate of 680Kbps and has a lifetime for more than 15.000 transmission cycles. The group has been in dialog with both Ocean Forrest and WSENSE throughout the project and have ascertained that their modem can be used and that they can also provide the surface unit with a graphical user interface.

However, for prototyping and testing within the time limits of this project, it was found out that another setup of electronics was needed for several reasons. It was not planned that the current prototype is going to be able to be tested in water as most of the initial tests are most useful to perform in dry air. However, an acoustic modem intended for use in water will not work well in dry air. There are also limitations with how a signal from a modem is going to result in movement by the actuator.

For testing purposes, the plan is to use an Arduino micro for receiving the signal and driving the actuator which is externally powered. Another problem that occurred is that the modem would have to be shipped to Norway from Italy and that would have taken some time in addition to having to sit down with the employees from WSENSE to figure out a reliable testing setup which proved to be difficult during the global covid pandemic and the restrictions that comes with it. The group decided to simulate the modem by using a ESP8266 Wi-Fi module that communicated with an Arduino Micro and a cellphone. In backup, the Arduino and Wi-Fi module could be replaced by an RC-receiver. The following components are used in the second prototype:

Source of power:	1 x 9-volt battery	
Communication:	1 x Arduino Micro 1 x ESP8266 Wi-Fi module **OR** 1 x FrSky D8R-II plus RC-receiver	Simulating modem
Linear actuator:	1 x Actuonix PQ12 Miniature Linear Actuator	
Voltage step down module:	Welleman VMA404 DC-DC adjustable voltage step down module LM2596S	

Table 4.1: Electronics specifications

The linear actuator is performing the important task of lowering and raising the locking pins. It is attached with a bracket in the bottom of the electronics compartment located in a parallel and coincident vertical line of the locking pins. The shaft is connected to a threaded rod that goes through both locking pins and the actuator. The actuator is running on 6 volts and can lift around 50 N. The linear actuator is connected to, depending on the prototyping setup, either an acoustic modem, an Arduino Micro or a RC-receiver (shown in figure 4.7). Since the battery is providing 9 volts, there is a need for a step-down voltage regulator to regulate the voltage down to 6 volts. Circuit diagrams and data sheets are provided as attachments.

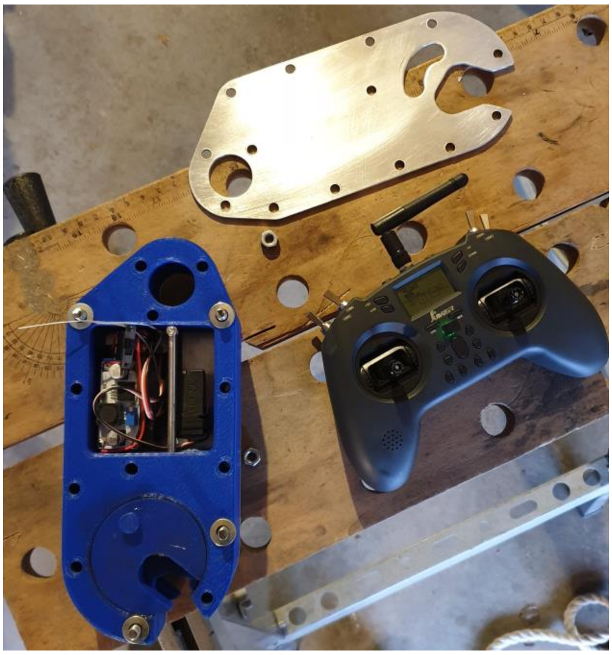


Figure 4.7: Actuator connected to RC receiver *Figure 4.8: Assembly of the components*

4.4 Material Choices

The zone between air and sea as well as the upper layer of the sea is one of the toughest and harshest environments that one can place equipment. There is always a constant threat from the dynamic forces from the sea and weather. In terms of corrosion, it is one of the worst environments because of access to saltwater and oxygen, especially if the equipment is exposed to both elements and being constantly washed over by sea and rain. Because of the low depth of the equipment placement, the exposure from the sun will have a significant effect on the material of the clip.

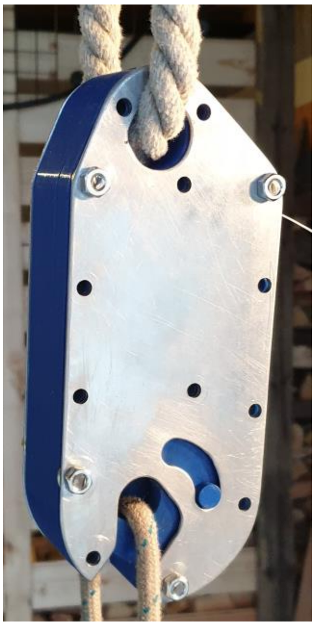
In this project, the equipment is being used for growing seaweed so naturally it will be placed in the area of the sea where it is most favorable for the growth. This is good in terms of seaweed production, but algae growth on the clip can be a big threat. It could for example immobilize the modem and transducer's ability to send and receive signals. Algae growth can also block the mechanism to release. To cope with these two future challenges, it was designed that the clip was to be as encapsulated as possible with most mechanisms placed internally with no open areas for algae to grow that could possibly block the wheels rotation.

Secondly, it will be recommended that if the modems transducer needs to be located in direct contact with the seawater, to then place a protective cage around the transducer to protect it from physical forces acting on it and also, if possible, to utilize a matching layer on the transducer that is somewhat growth inhibitory for at least some months submerged. When the operators are harvesting the seaweed, it is recommended that they clean of any growth on the transducer.

In terms of material choices for the clip itself, some or most of the layers could be made of a polymer such as polyethylene which is tough, durable and corrosion free. However, metal is far superior in terms of tensile strength and toughness generally and it is recognized that it might be needed to make wheels and wheel housing layers in some sort of stainless steel or aluminum. There could also only be needed to make the outer layers out of metal and getting the collective strength of the clip from the bolts going through all layers. In conclusion, the only way to find out is to firstly measure and make an estimate for the force that the clip needs to hold and then find out best material choice and combination by performing strength calculations and analyses both on computer and with real life tests in the future.

5. Results and Discussion

Some tests of the second prototype were performed late in the project, but with a great outcome of hands-on experience with the clip and how it works in real life. There has been one main test for the most part that has been used to assess how the mechanism and clip as a unit works. The test has been to simply suspend the clip from the ceiling with a rope and attach a rope loop with a 4kg weight attached to it as seen in figure 4.9 and 4.10.



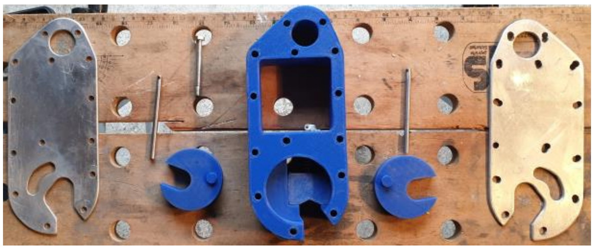


Figure 4.9 Testing *Figure 4.10: Closeup of clip* *Figure 4.11: Overview of clip components*

After performing a few basic tests, it was clear that the clip worked well. Inserting the rope worked fine and the locking pins was driven smoothly down into the wheels by flipping a switch on a RC-remote. A 4kg load was no problem at all and it could certainly hold much more weight. The clamping of the rope worked excellently and assures that ropes with different diameters and textures was firmly clamped in place. When the release command was given, the rope loop was dropped immediately by only the weight. The size of the clip as a unit is satisfactory small and feels sturdy even from 3D-printed material. Overall, the testing has given the group a valuable insight in how the clip works and how it could be improved on in the future.

Here are the key points that the group found most important to further develop and improve on:

• The locking mechanism consisting of the linear actuator being directly attached to the locking pins is regarded as the most unfinished and problematic area. A problem that the group acknowledged was that the operator needs to hold the rope and the wheels in position simultaneously as he or she sends the command for lowering the locking pins down. This is recognized as tedious, and it also introduces a problem where if the locking pins path is blocked, serious damage can occur if they are lowered without attention. A solution to solve this problem would be to make the pins spring loaded so that they push towards the wheel. When the wheels get aligned, the pins get lowered in the shafts on the wheels and locks them in place by itself.

• Performing strength calculations and real-life tests on the clip is regarded as something that has to be done at one point to find out its limit or assess weakness points where the design could be improved.

• Adding redundancy in form of an alternative failsafe method to open the clip if a fault with the electronics occurs.

• Improving grip for the operators on the wheels, so that it could be operated with for example gloves on.

• The final electronic package in itself is something that has to be developed and designed for the final clip product.

6. Conclusion

The aim of the project was to explore how underwater communication could be combined with an efficient design to be implemented in a solution for automizing the reaping process for the seaweed farming business. A given subject was given regarding improving a clip used for holding the seaweed growth rope. Relevant communication technologies were studied, with the goal in mind of finding the most suitable one for the project. The theoretical analysis regarding the communication showed that UWAC would be most advantageous in this context. This knowledge was necessary to properly conduct continue with the next step, which was developing a structure and mechanism design.

Firstly, with the knowledge of what was required to be inside the clip to perform the automized actions, which where remote opening; the clip would also need to room all the components whilst maintaining the ability to its primary tasks.

Secondly, a structure that take the previously mentioned factors into account was designed with 3D-modelling and in turn, 3D printed for prototyping. All the necessary electrical components for prototyping like battery, actuator, Wi-Fi modem and a small circuit board were fitted inside the given compartment to test the remote-controlled opening mechanism. As shown in Figure 4.8, there were room for every component, and the mechanism worked as it was designed.

This project has shown that it is indeed possible to develop a solution consisting of the joint resources from the underwater communication industry and the mechanical competence from the group. However, it requires further testing and development to finally determine the parameters or discover possible liabilities that may occur under operating conditions that is not easily replicated in a lab or in a garage.

The work performed in this report do lay a foundation for a continuously development around the prototype with the goal in mind to fully automize the seaweed farming process. Further development should include normal-scale testing with the actual load that will act upon both the structure and the locking mechanism with a full-grown seaweed line ready to be harvested. This way, it can be completely determined the level of feasibility of the concept.

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