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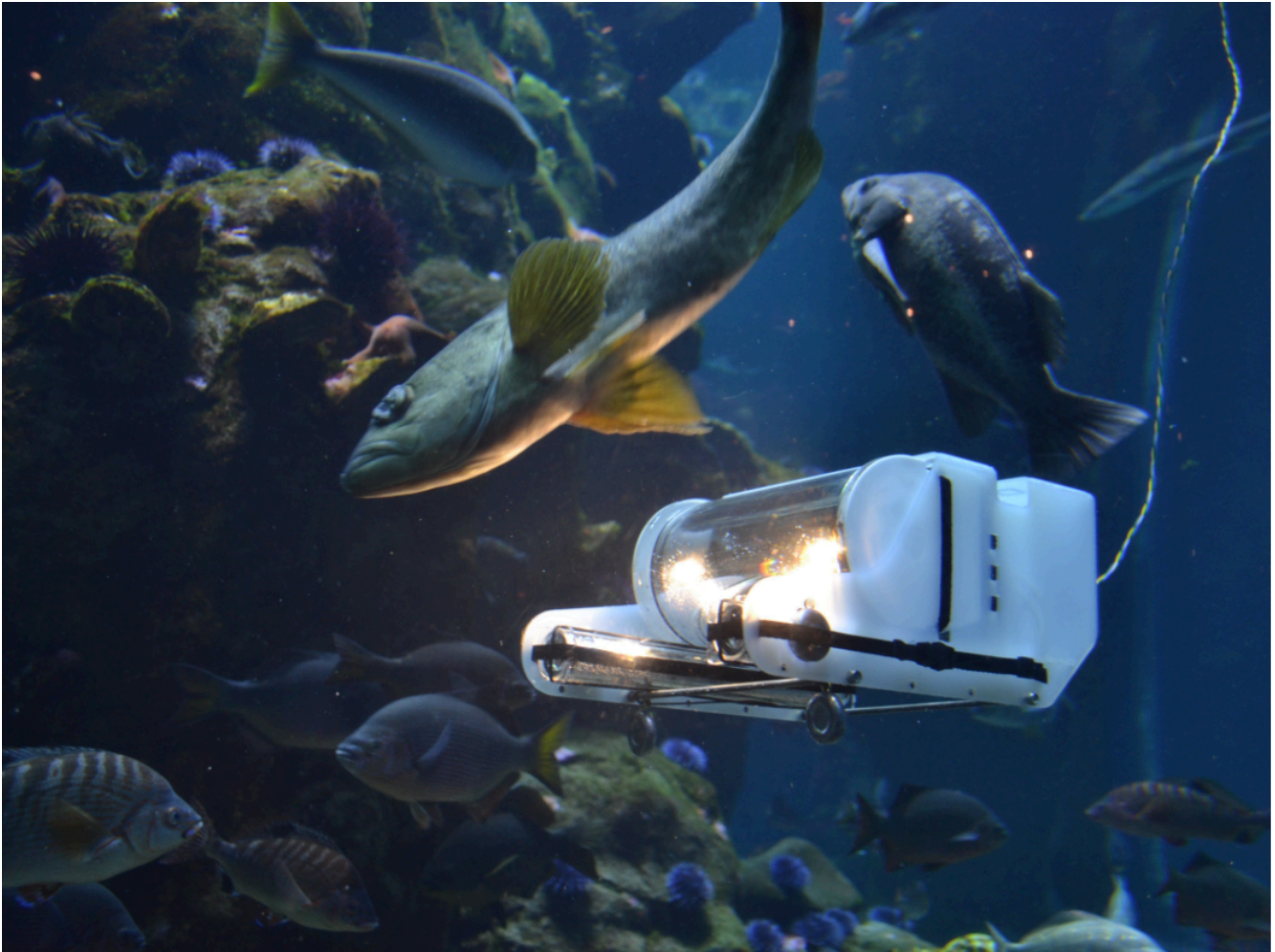
Study of potential for Micro-ROVs for Underwater Monitoring, Applications and Market

En mulighetsstudie for mikro-ROVer til
undervannsovervåkning, applikasjoner
og marked.

Christine Spiten

Study of potential for Micro-ROVs for Underwater Monitoring, Applications and Market

By
Christine Spiten



Master thesis at The Norwegian University of Life Sciences
Department of Mathematical Sciences and Technology

2015



*No water, no life
No blue, no green.*

- Sylvia Earle

PREFACE

This master-project is the final step in my 5 years of studies for the degree Master of technology in Industrial Economics at the Norwegian University of Life Sciences. The project work has been carried out at the Department of Mathematical Sciences and Technology.

My main motivation for this study is to learn more about environmental monitoring and how innovative technology can provide useful tools to face challenges caused by climate changes, growing population and hence, increased consumption and increased wastage.

Growing up in Norway, a country known for its beautiful coastline and fjords, being an active sailor spending hours a week on the ocean, I have always found the world beneath the surface intriguing. Happy to live in a time where access to this world is possible, I am genuinely motivated to use this possibility to learn more about it. Working for OpenROV has taught me to be curious and open-minded within this field of study, which has proven valuable during this project.

Working on this thesis has been exciting, challenging and educational. There is a lot of work behind the final version of the thesis, and the learning process has been invaluable. There are many persons that have contributed to this work, whom I will like to thank.

First of all, I want to thank my main supervisor, Associate Professor Jan Kåre Bøe, for his engagement and support along the way. He has given invaluable advices, been patient and understanding. Thanks to my second supervisor, Associate Professor Pål Johan From, who took the author and co-students to Brazil for three weeks to learn about robotics, and for contributing to the scientific paper for the SYROCO Conference. I also want to express gratitude to Pål's wife, Carla for being a great hostess and organizer in Brazil.

Professor Ian Bryceson has shared with me valuable knowledge about coral reefs and marine ecology, as well as introducing me to the endless world of technical sensors, and for that I want to thank him.

Thanks to the OpenROV crew; Founders David Lang and Eric Stackpole, Product Manager Zack Johnson, National Geographic Explorer Erika Bergman and my good friend and colleague; Dominik Fretz for enormous inspiration, motivation and valuable feedback. Thank you all for sharing this great adventure with me!

I would also like to thank my family; my mom and my dad for their invaluable support.

Ås, May 14th 2015

Christine Spiten

ABSTRACT

The need for eyes under water has increased significantly as more and more industries are based on marine resources, such as energy, food production and transportation. Along with these industries other services have also been established within safety and rescue, and scientific research have increased.

This report constitutes a feasibility study of micro-ROVs as tools for underwater monitoring, focusing primarily on three market areas;

1. Environmental monitoring – specifically on coral reefs
2. Aquaculture
3. Rescue and safety service

By introducing the reader to the history of underwater technology, from the first attempts for humans to stay under water, to today's technology, that has taken us down to the deepest point on Earth, this report gives an understanding of the background for exploring the urge and work behind us on the evolution in this field.

The aim of this project is to identify potential applications for small ROVs and on the basis of these propose solutions to meet existing market needs. Existing concepts are examined and compared with each other, and interviews and discussions with experts from each industry are undertaken to uncover "where the shoe pinches" and potential needs for micro ROVs.

Based on the findings from this research, technical tests have been conducted to determine whether OpenROV v2.7 meets the various sectors' needs, and reveal possible improvements.

Furthermore, there is developed a concept in which sensors for pH and oxygen measurement is implemented on an OpenROV and testing of the concept is done. On the basis of these tests it is suggested modifications and enhancements to further work.

OpenROVen is compared with alternative solutions for underwater surveillance and cost, availability and ease of use are analyzed and presented at the end of this study.

It has been shown in this thesis that there is need for micro-ROVs for surveillance within the concerned industries, and that it is feasible to meet these needs. It was also determined that the price is an important factor for the degree of implementation of such systems within smaller enteties. There are however many uncertainties, since a large part of the study is conducted theoretical and since the developed models have not been tested under real conditions.

SAMMENDRAG

Behovet for overvåkning under vann har økt betraktelig etter hvert som stadig flere næringer er basert på marine ressurser, slik som olje, energi og fisk. Sammen med disse næringene har også andre tjenester innen sikkerhet og redning, samt satsning på FoU tiltatt.

Denne rapporten utgjør et mulighetsstudie for bruk av mikro-ROV som verktøy til undervannsovervåkning med fokus på tre ulike markedsområder;

1. Miljøovervåkning av korallrev
2. Overvåkning ved oppdrettsanlegg
3. Rednings-dykkertjeneste.

Ved å innvie leseren i undervannsteknologiens historie fra de første forsøkene på å oppholde seg under vann, til dagens teknologi som har tatt mennesket ned til det dypeste punktet på jorda, vil denne oppgaven gi noe av grunnlaget for drivkreftene til videre utvikling på dette området, basert på tidligere oppnåede resultater.

Målet med dette prosjektet er å avdekke mulige bruksområder for små ROVer og ut ifra disse foreslå løsninger for å møte eksisterende markedsbehov. Eksisterende konsepter er undersøkt og sammenlignet med hverandre, og intervjuer og samtaler med eksperter fra hver bransje er foretatt for å avdekke ”hvor skoen trykker” og potensielle behov for mikro-ROVer.

Basert på funnene fra disse undersøkelsene samt litteratur som underbygger disse, har det blitt gjennomført tekniske tester for å avgjøre om OpenROV v2.7 oppfyller de ulike bransjenes behov, og avdekke hvilke eventuelle forbedringer som må gjøres.

Videre er det utviklet et konsept der sensorer for pH- og oksygenmålinger er implementert på en OpenROV og testing av konseptet er utført. På bakgrunn av disse testene er det foreslått modifikasjoner og forbedringer til videre arbeid.

OpenROVen er sammenlignet med alternative løsninger for undervannsovervåkning basert på kostnader, tilgjengelighet og brukervennlighet. Resultatene fra sammenligningen er analysert og presentert til slutt i denne studien.

Det er vist i denne avhandlingen at behovet for mikro-ROVer til overvåkning innen de omhandlede næringene er tilstede, og at det er gjennomførbart å løse oppgaver på disse områdene. Samtidig er det blitt fastslått at pris er en avgjørende faktor for grad av implementering og nyttegjøring av slike systemer, og samtidig årsaken til at mindre aktører velger å ikke anskaffe en. Det er imidlertid flere usikkerhetsmomenter, ettersom store deler av studien er utført teoretisk og at de utviklede modellene ikke er testet under reelle forhold.

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ABBREVIATIONS

Table 1: List of abbreviations

Abbreviations	Meaning
AUV	Autonomous Underwater Vehicle
CAD	Computer-aided design (CAD) is a computer system that can be used to assist in creation, modification, analysis or optimization of a design
DC	Direct Current
DIY	Do It Yourself. A movement or trend of people getting into making products instead of buying
DoF	Degree(s) of Freedom
GPS	Global Positioning System
ICRI	International Coral Reef Initiative
IMU	Inertial Measurement Unit; provides information about the vehicle's linear acceleration and angular velocity
I2C	Inter-integrated Circuit, a serial computer bus used for attaching lower-speed peripherals to the main PCB
MWS	Meeting with supervisor
NMBU	Norwegian University of Life Sciences
PCB	Printed circuit board. Supports and connects electronic components
ROS	Robotic Operating System
ROV	Remotely Operated Vehicle
UFRJ	Federal University of Rio de Janeiro
UVMS	Underwater Vehicle-Manipulator System

1 INTRODUCTION

This study gives an insight to the fields of applications and market for underwater surveillance and suggests potential solutions using micro-ROVs.

1.1 Motivation

In February 2014 the author went to a Maker Faire for the very first time, not at all prepared for the outcome. It turned out to be the first step into the underwater world.

At the faire was Eric Stackpole, the founder of OpenROV – a small startup company based in San Francisco, California. Eric gave a thrilling presentation of the history behind OpenROV, and told how he and his friend, David Lang, had invented the first ROV as a tool to help them in the hunt for a hidden treasure!

Today OpenROV have sold more than 2000 OpenROVs, and the first version has developed drastically into new models that can go deeper, and are more reliable. The size and price of the OpenROVs make them available for a large number of people who wouldn't have had the opportunity to buy an ROV otherwise. The way the company has made everything "open source" is encouraging curiosity and invites to adventures, and thus makes OpenROVs a great product for educational and explorational purposes all over the world.

For as long as I remember, I have been drawn towards the ocean. I have always been fascinated by and strived to learn more about this unseen world hidden below the waves. All life on earth is depending on the oceans that covers 71% of our planet, and we would not exist without it. It is believed that there are more living species in the ocean than on land, and knowing that only 5% of the ocean that is discovered gives a picture of biodiversity (NOAA, 2014) (BBC News, 2014).

In a report recently compiled by Global Change Institute at University of Queensland and Boston Consulting Group, the value of the worlds oceans is in total estimated to be over 24 trillion US Dollars, or 181 trillion NOK. These numbers are based on the value of fishery and aquaculture, tourism, shipping and ecosystems such as coral reefs and mangroves and do not take into account the values from the energy industry; oil and ocean based wind parks. This report gives a rough but quantified economic value and thus provides a concrete picture of how important the sea is (Tronhaugen, 2015).

1.2 Background

Underwater robots have seen a tremendous decline in price over the last few years. This thesis enlightens how this decline in price can leverage the use of underwater robots in new application areas, and in particular environmental monitoring. The main focus of this work endeavors to equip the robot with the necessary sensors needed for monitoring and surveillance, and at the same time keep the overall cost of the robot low. This is challenging as some of the sensors normally used are rather expensive.

For that reason this thesis will propose affordable sensors that can be mounted on the robot, and investigate how existing on-board sensors can be used, such as cameras together with advanced image processing and sensor fusion to improve performance without increasing the overall cost of the robot.

1.2.1 Evolution in submersibles

Throughout history people have been drawn towards the unknown, pushing physical and theoretical limits to reach the highest mountains, to fly and even travel to space. The ocean has not been bypassed and still, as mentioned earlier, we only know about 5% of it. Our incapability to breath under water is of course the main reason for this lack of knowledge and an obstacle that require technological development and innovation. This has made research on marine biology and the ocean complex and challenging. However, the technological development is increasing in speed, and by taking a look at the history, one can see that a lot has happened over the last decades.

As early as the 15th century, Leonardo da Vinci made the first known drawings of an underwater breathing apparatus. He did not explain the system in detail due to what he described as “bad human nature” would take advantage of it to sink ships and even commit murders. However, the drawings that were found, shows that the apparatus consists of cane tubes attached to a face mask and at the other end to a bell-shaped float to keep the openings above water. (British Library)

In 1870 the novel *Twenty Thousand Leagues Under the Seas* written by the French author Jules Verne, was published. It is the story about Captain Nemo and his submarine Nautilus. The description of Nautilus was considered ahead of its time (Whitman, 2004).

In 1943 the French naval captain, Jacques-Yves Cousteau and Emile Gagnan developed the “Aqua-Lung” concept, the first modern SCUBA gear incorporating an automatic demand valve to release air as the diver inhales, and thus liberated divers from tethers and hoses. This system was used to shoot the first underwater film by using scuba sets. The film was called *Shipwrecks*.

The deepest point of the ocean is within the Mariana Trench in the Pacific Ocean and is called the Challenger Deep, named after the British Royal Navy survey ship HMS Challenger, from where the first recordings of its depth were made in 1875. Modern methods have measured the maximum depth to be 10 994 meters. People have been able to go all the way down there six times, the first time was in 1960 when the Swiss deep water scientist Jacques Piccard and the American marine officer Don Walsh went down with the submarine, Trieste. It took them five hours to reach the bottom, where they stayed for 20 minutes. Not until 1995 the sea bottom of Challenger was investigated, this time with the Japanese AUV, Kaiko (Barry & Hashimoto, 2009).

On September 1st, in 1985, oceanographer and former Navy captain, Robert Ballard together with a team of American and French researchers located the Titanic, the world's most famous shipwreck, at a depth of 4000 meters, 640 kilometres off the coast of Newfoundland. On their mission they used a system of television cameras and sonars called Argo (see Figure 1).

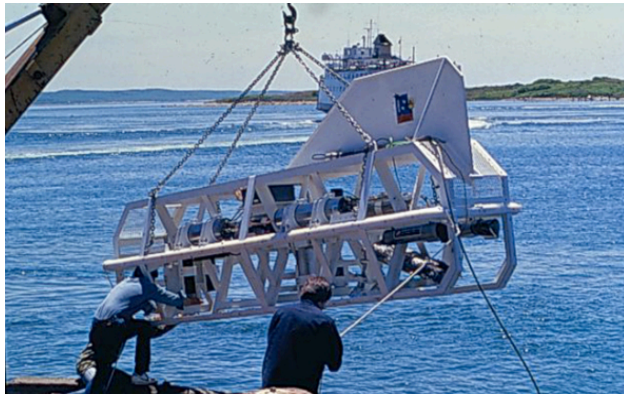


Figure 1: Argo. (Photo: WHOI Archives)

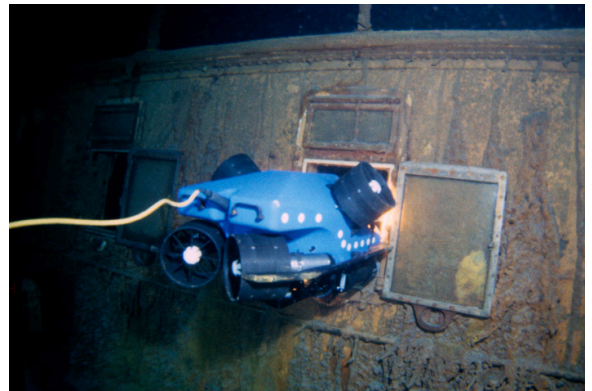


Figure 2: Jason Junior. (Photo: WHOI Archives)

During the Titanic return mission in 1986, a small ROV called Jason Junior (Figure 2), developed by WHOI (Woods Hole Oceanographic Institute) Deep Submergence Laboratory was used. Jason Junior (also called JJ) made scientists able to explore places where Alvin, the system of television cameras and sonars, on which JJ was attached by a 100 meters fiber optic cable, could not fit (Woods Holde Oceanographic Institute, 2012).

In 2012 - 52 years after Piccard and Walsh – movie director and explorer, James Cameron, became the third human being in the world to experience Challenger Deep. This expedition was carried out with the submarine vessel, Deepsea Challenger, that was equipped with a hydraulic manipulator arm for taking samples and with multiple cameras for capturing images of the landscape and life-forms in some of the world's deepest zones.



Figure 3: James Cameron on top of Deepsea Challenger. (Photo: pcmag.com)

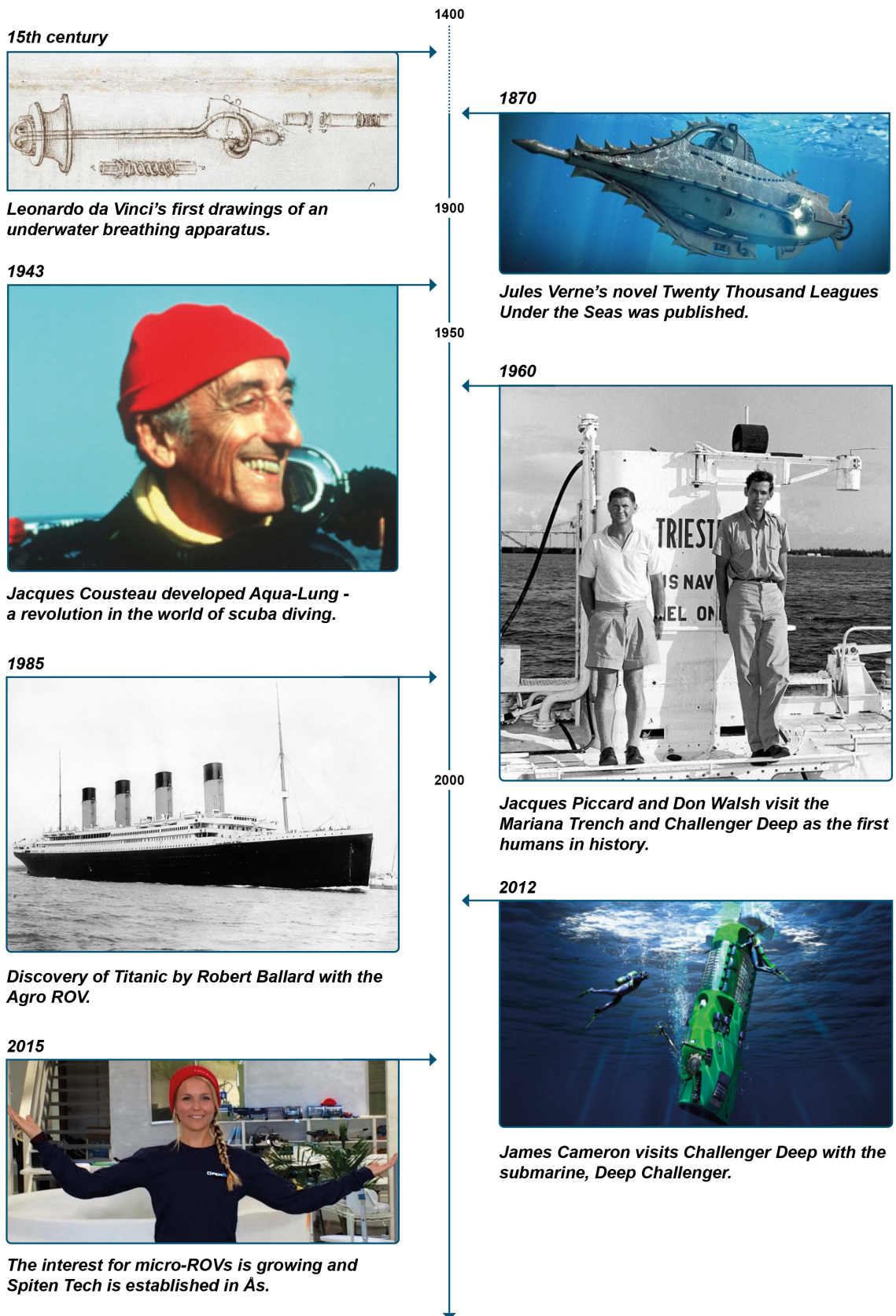


Figure 4: Timeline of evolution in submersibles.

Recently ROVs have provided important service in emergencies;

- The Remora 6000 ROV retrieved the black box of Air France flight 447 that crashed off the coast of Brazil in 2009. Controlled through a 6.700 meter long fibre optic cable, the ROV located the box at 3900 meters depth.
- After the Deepwater Horizon catastrophe in the Mexico Gulf in 2010 – considered the largest marine oil spill in the world, and the largest environmental disaster in U.S. history – ROVs were deployed to stop leakage and to monitor the oil spill in the following weeks and months. (From, Pettersen, & Gravidahl, 2014)

Today underwater robotics are used in multiple fields of industry, whereas the main is the offshore industry using different robots for inspection of subsea installations and hull inspections. As many other technical devices, ROVs have also decreased in size while at the same time been given more functions and capabilities, that have opened up for new areas.

1.2.2 The potential of small ROVs

In recent years, prices of technology have decreased significantly and private individuals have thus gained access to tools that were previously reserved for the industry. ROV's are no longer available only to wealthy companies, but serve as tools for *citizen scientists* and smaller operators for scientific and educational purposes, inspection or monitoring of different parameters on more shallow waters.

The summer of 2014 sea stars were mysteriously dying along the Californian coast. From Seattle all the way to San Diego, dead star fish were found, and there was no answer to why. This is an example of an occasion where private individuals turned into citizen scientists and assisted scientists and biologists by registering locations and numbers of sick and healthy sea stars, and thus contributed to create a map. Some of them used OpenROVs to search on deeper waters (James, 2014).

1.2.3 OpenROV

One of the main objectives of this work is to investigate possible solutions for sensory systems and thus decide on sensors for the OpenROV v2.7 to become a useful tool for monitoring water quality and environmental parameters that affect living species such as fish and corals. Applying low-cost sensors, advanced data fusion and image analysis in such a way that the necessary information is obtained, and at the same time keep the cost low, may be crucial for the future opportunities for OpenROV as a monitoring tool.

For both environmental monitoring, scientific research, and for the aquaculture industry, measurements of water quality is vital, and the parameters to be measured are often the same; pH-level, oxygen, salinity and turbidity are the most common.

1.3 Problems and challenges

This project examines how to utilize a small ROV for underwater monitoring. Furthermore there is a practical part of the project with the goal to develop solutions to meet potential challenges and implement sufficiently advanced sensory systems.

Technological challenges

During practical testing, there are some technological challenges that are expected to arise:

- Data and signal transmission through deep water
- Waterproof casing for sensory systems, due to pressure forces
- In order to keep the OpenROV an affordable system, the sensory components need to be made in such way that the price is kept low
- Space and weight constraints on the sensory system, to minimize disturbance of buoyancy and hydrodynamic properties and motion of the ROV

2 PROJECT PLAN

This semester has consisted of numerous activities on several arenas which all have led towards a common goal; to work with ROVs. Working on this thesis has been a valuable opportunity to explore the market while at the same time establishing a company, Spiten Tech.

In parallel to working on this project, the author has held courses in building OpenROVs, given talks at the University and been involved in multiple ROV-related projects. In the autumn the project will be taken even further when new student projects will be established by NMBU as a continuation of this task. There have been busy months and thus essential to maintain a steady course. This chapter presents the project plan, and describes the objectives that has led the way.

2.1 Main goal

The following goal has been defined for this project:

To investigate the potential of a small remote controlled submarine (OpenROV) as a tool for surveillance within three fields of applications;

- Environmental monitoring
- Monitoring around, and on aquaculture sites
- Rescue and safety missions

Furthermore evaluation of customer needs, technological and economical aspects have been crucial. A goal should fulfill each description in the abbreviation SMART (Samset, s. 144);

- Specified – easy to understand
- Measurable – the method for measurement should be given. Milestones is one example
- Accepted – all involved should accept the goal for the work
- Realistic – the goal should be obtainable in relation to available resources
- Time limited – the deadline shall be clarified

2.2 Part Goals

In order to achieve the main goal, some part goals has been set that need to be fulfilled. Along the way, those goals have been measured against performed activities and mile stones to apportion the time spent as the deadline is nearing. This section gives a short introduction to the part goals followed by the work schedule.

- Search for relevant literature and expertise in the fields of underwater monitoring and robotics and thus build a preliminary base of knowledge
- Write early review of alternative solutions
- Learn about applications in small submersibles, potential and technical limitations
- To perform concept testing and system selection

2.3 Milestones

Throughout the work on this project there have been several meetings between the author and the supervisor. These meetings have served as milestones where one has reviewed the progress of the project, discussed challenges, rectified mistakes or misunderstandings, and corrected before new part goals have been set, until the next meeting. Meetings with representatives from the different application fields have also been decisive to the progress, because the procurement of components for testings have relied upon their input.

The milestones are presented with a red colour in the work schedule in Figure 4 and described in more detail in chapter 2.4.

- Meeting with supervisor (MWS) to define problem and scope of the thesis
- Exam in general robotics March 5th
- Meeting with representants from the rescue service, demonstration of the OpenROV
- Meeting with Marinbiologene
- Evaluation MWS – discuss progress and set new part goals based on research findings
- Final MWS
- Hand in thesis and prepare presentation

Table 2: Schedule for meetings with company representatives

Date	Company	Subject	Location
10.03.2015	Oslo Fire & Rescue Service	Use of ROVs for rescue operations	Oslo
18.03.2015	Norsk Gjenvinning	Use of ROV for mapping of wrecks	Oslo
20.04.2015	Imenco, SeaBotix	Mini-ROV	Haugesund
01.05.2015	Miltronic	Mini-ROV market situation	Drammen

2.4 Project schedule

The project plan shows the activities, surveys and meetings during the work on this thesis. Each milestone have got a red color to stand out from the other activities as important deadlines.

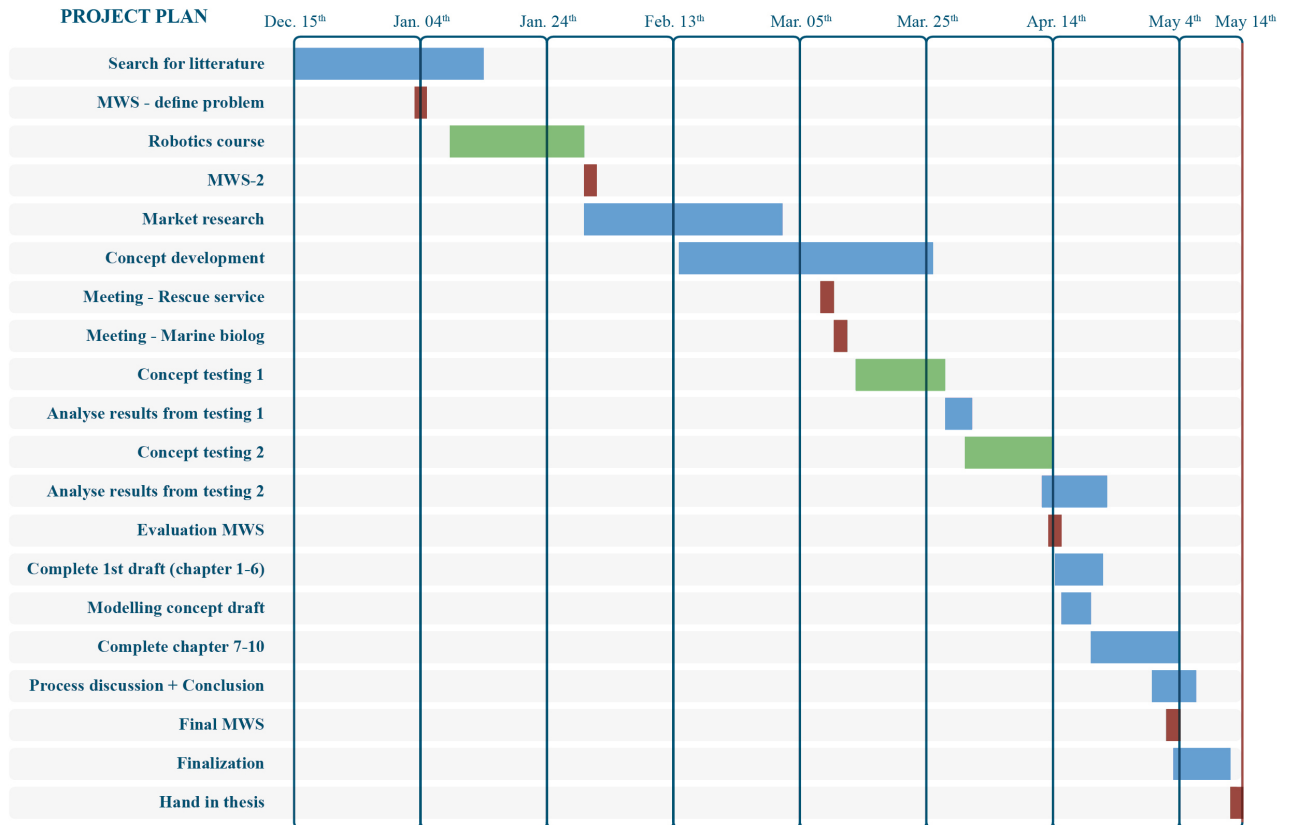


Figure 5: Schedule of activities and milestones. Blue colour indicates research related activities, green practical activities and red are deadlines and external meetings.

2.5 Limitations

Due to time constraints of 900 hours available during the semester, the following focus and frames are included in the work with the project:

- The study is limited to focus on the following three fields of application; environmental monitoring, marine aquaculture and rescue service
- Meetings and personal conversations that are planned will only be done with a selected group of people
- Conceptual design in brief. Prototyping will be done during summer/autumn 2015
- The testings will be performed with tools and equipment that is available

The following are not considered in this thesis:

- Conceptual changes on the OpenROV design beyond those that are necessary due to implementation of chosen sensory system

To perform the two tests, some components were needed. The budget, based on prices from online retailers, is as follows:

Table 3: Budget for technical components

Component	Retailer	Price	TAX/Shipping
Arduarium Ultimate controller	Proto-Pic	\$165,0	-
pH-probe	Atlas Scientific	\$72,0	\$50,0
Oxygen probe	Atlas Scientific	\$198,0	
Arduino Uno	Arduino shop	\$25	-
EZO pH Circuit	Atlas Scientific	\$34,0	\$50,0
EZO DO Circuit	Atlas Scientific	\$40,0	
Single Circuit carrier board	Atlas Scientific	\$22,0	
Total:			\$ 656,0

3 POTENTIAL AREAS OF USE

There are several areas in which a small ROV is useful. In this project the focus is on application fields where monitoring of water quality or underwater investigation of inaccessible places, or even a combination of the aforementioned is needed. This chapter presents the three main focus areas; environmental monitoring, marine aquaculture and rescue service, and explain potential applications within each area.

3.1 Surveying environmental health in reefs

The health of coral reefs is important, not only to the thousands of species living on them, it also affects biodiversity in the surrounding areas as well as the humans living in coastal communities. In addition to provide food and spawning areas for fish, reefs often serves as natural breakwaters protecting coastal areas from the increasingly wild weather. Coral reef declines will have emerging consequences for approximately 500 million people who depend on the reefs for their livelihoods, for food, coastal protection or income from tourism. Conservation of coral reefs is thus important to maintain balance in fish populations. Moreover coral reefs have shown to have an greater impact on the ocean's CO₂-level than previously anticipated. It is estimated that tropical reefs take up to 2% of the man-made CO₂ (Hovland & Mortensen, 2008).

Distribution

Corals are distributed in every ocean, both shallow and deep water, but the cold-water corals look very different from the corals in tropical water. That is because the algae living in the tissues of tropical corals need light for photosynthesis. Warm water is defined as water with temperatures between 22-29°C, and cold water as water with temperatures lower than 22°C, the map in figure 5 shows where the corals are found.



Figure 6: Distribution of cold water and tropical coral reefs. (Photo: Hugo Ahlenius, UNEP/GRID-Arendal)

Threats

There are multiple threats to coral reefs, whereas bleaching is one of them. When corals are stressed by changes in conditions such as light, temperature or nutrients, they expel the symbiotic algae living in their tissues, and thus obtain a bleached white colour before they eventually die. Increasing concentrations of dissolved CO₂ is another threat to corals, as more carbon dioxide in the ocean makes it more acidic. This will in turn damage the coral's skeleton. Diseases, plagues and invasive species are other threats. Excess sediments flowing off the land and pollution by nutrients and chemicals from agriculture and industry are increasing problems for biodiversity in coastal areas. Over-fishing and destructive fishing methods such as trawling and fishing by use of explosives is directly harming the reefs and may destroy large areas completely.

GCRMN's report on the status of coral reefs from 2008 provides detailed description of each of the aforementioned threat and enlightens additional pressures on coral reefs [Wilkinson, 2008]. Although knowledge about coral reefs and actions taken to preserve them have increased over the past 20 years, there are many aspects that remains uncovered, and the conditions on coral reefs are in constant change.

Conservation

Monitoring of underwater habitats, particularly in and around marine protected areas (MPAs) requires non-destructive observation methods allowing the reefs to stay unaffected by the monitoring activities itself. The current methods used to monitor coral reefs are done very cautious, but unfortunately also very time consuming and imprecise, namely by divers conducting surveys manually. Under acute ecological interferences such as massive pollution emissions, outbreaks of disease, mass bleaching or hurricanes, it is needed to quickly assess changes and survey large areas at the same time.

There is thus reason to believe that access to small ROVs that can take measurements and record video, will be a useful supplementary to divers and allow more quickly analysis of the conditions based on the real-time data sent to surface where the ROV-pilot may have good overview of both video and measurements of water quality at the same time.

Monitoring methods

Today, monitoring of coral reefs is mainly visual, i.e., measurements of colour, size, and mortality conditions of the reefs often done by trained volunteering scuba divers conducting surveys run by organizations. Such surveys usually takes many weeks to perform, much because of the analysis process that follows.

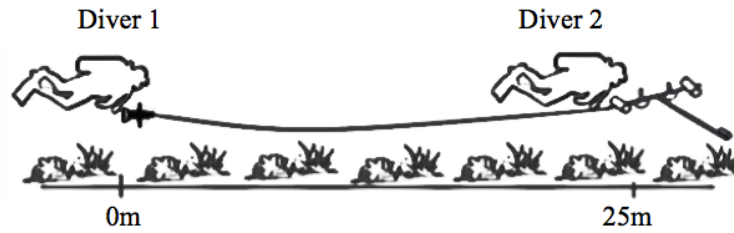


Figure 7: Divers using the stereo-DOV system. Diver 2 communicates with the camera operator (Diver 1) using tape reel. Diver 2 remains at the start of the transect as Diver 1 swims ahead capturing video footage.

The challenge for monitoring programmes is to choose those survey techniques which most accurately and precisely address the ecological question of interest (Watson et al., 2010).

Pictures from ROVs under water will provide the necessary information on colour - whether the corals are pale, bleached or having its normal color is simple to see from the video recording. An idea is to combine the use of ROV with drones to get a picture of the size of the reef.

3.1.1 Brazil

Brazil has a coastline stretching 7,491 kilometers from 33° south to 5° northern latitude, enriched with beautiful coral reefs. Overall, inshore reefs of Eastern Brazil which are located less than 5 km from the coast, are in poorer condition than the offshore reefs, which are located more than 5 km off the coast. The inshore reefs have been experiencing stress resulting, chiefly, from higher sedimentation rates and water turbidity (Dutra, Kikuchi, & Leao, 2006).

Brazil joined the International Coral Reef Initiative (ICRI) in 2006 which is an informal partnership between nations and organizations to preserve coral reefs and related ecosystems. Since then the number of monitoring sites have increased as well as the number of protected areas. One of the fully protected areas is the Abrolhos National Marine Park off the Southern coast in the state of Bahia.

Bahia is also the region whereas surveys for this thesis have been conducted along with the robotic field course on UFRJ. In Figure 7 the corals along the Bahian coast are marked in red.

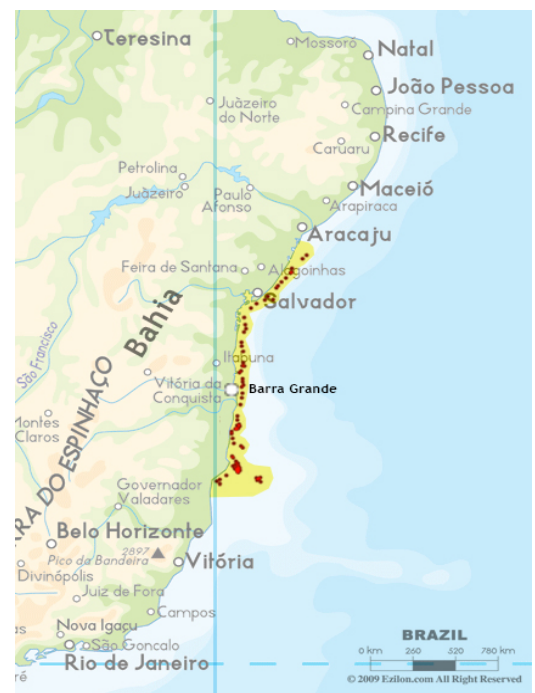


Figure 8: Distribution of coral reefs off the coast of Bahia, Brazil. (Private illustration)

3.1.2 Norway

It has been said in the "Parliamentary report no. 12 (2001-2002)" that coral reefs are "...the most vulnerable type of marine species we have." It is believed that significant parts of the reefs in Norwegian waters may be damaged or dead, evidently mainly as a result of bottom trawling.

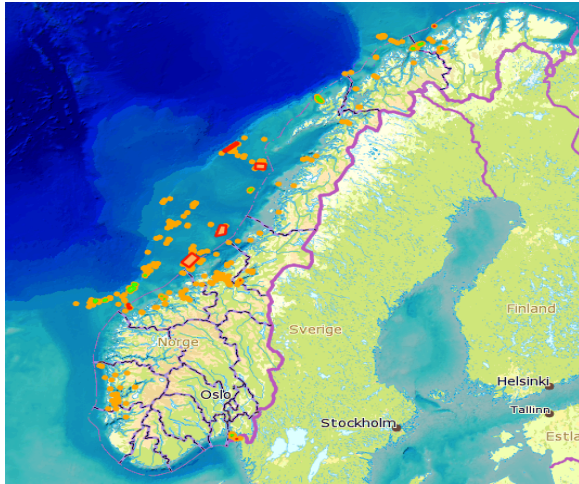


Figure 9-a: Appearance of coral reefs off the Norwegian coast. (Photo: Moreano)

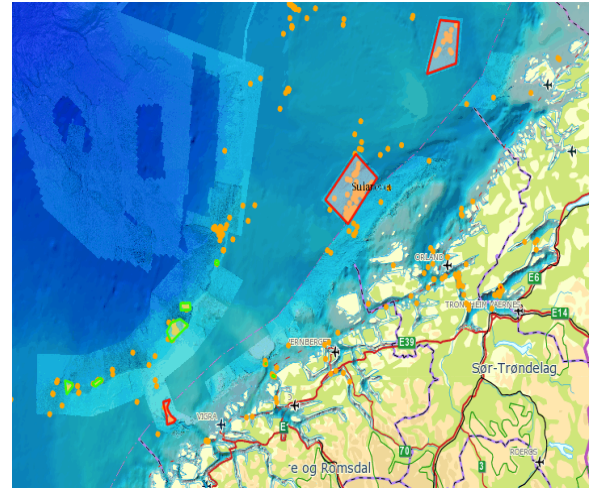


Figure 9-b: Appearance of corals off the coast off Trondheim. Orange being corals, red marks are protected areas and green are identified areas. (Photo: Moreano)

According to the Directorate for Nature Management's report from 2008, research has revealed some of the world's largest aggregations of the stony reef building cold-water coral, *Lophelia Pertusa*, on the continental slope off the coast and in the fjords of Norway.

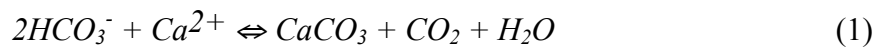


Figure 10-a: Lophelia Pertusa on the Malangsreef, Barents Sea (photo: Havforskningsinstituttet)



Figure 10-b: Close-up photo of Lophelia Pertusa. (photo: Havforskningsinstituttet)

Stone corals form their skeletons of calcium carbonate ($CaCO_3$) by binding calcium and bicarbonate (HCO_3^-) from the water after the formula:



Stone corals contribute to absorb CO_2 from the water and bind these in their skeletons.

A close related specie is *Madrepora oculata*, also a stony coral, but it does not form reefs. Horn Corals are softer and may resemble shrubs and trees in appearance, and is therefore called bubblegum coral or sea bush, and among the fishermen referred to as coral forests.

Corals grow on moraine ridges forming small hills or mounds on the continental shelf or inlet thresholds, but also probably on ridges and hard bottom in fjords. Schematically reefs are divided into three zones;

1. Top; we find mostly living *Lophelia* with only few other species, eg. bubblegum coral and further down rice coral.
2. The following is a zone dominated by dead and partially degraded corals that form a structurally complex habitat. Here is the diversity of add-on growth high.
3. At the bottom at the foot of the reef is a zone with coral gravel composed of small coral pieces in sand and mud. Here is the diversity of add-on growth lower than in the zone of, but as indicated in the figure, there are many sponges in this zone.

The large fishing and petroleum activities have led to greater mapping activity the shelf. Since the impact here is so large, it is especially important to identify what is there before it's too late. Nevertheless, one must not forget that coral and sponge communities in more coastal areas and in the fjords may be in conflict with a number of human activities. It is therefore important that the seabed in these areas is mapped in to accomplish greater knowledge on the marine biodiversity. It is also important to get as good an overview as possible of coral forests and other species than those that build reefs

3.2 Aquaculture

Globally, Aquaculture has been the fastest growing food production sector of the past 40 years and is continously growing. Now the industry supplies more than half of the world's food fish (Pendleton, 2012). In Norway fish farming has been an widespread and important industry since the 1970s when it began with salmon and trout farming in merdes along the coast. In Norway commercial farming of the Atlantic salmon, rainbow trout, cod and mussels is most common.

Norway is blessed with a long and rich coastline and, according to *The Norwegian Ministry of Trade, Indusry and Fisheries*, Norway is the world's leading producer of Atlantic Salmon and the second largest seafood exporter in the world. The aquaculture industry is providing close to 6000 jobs in almost 160 municipalities along the coast where other economic opportunities are

sometimes limited. In addition thousands of jobs are indirectly related to the aquaculture industry through supply, transportation and commerce.

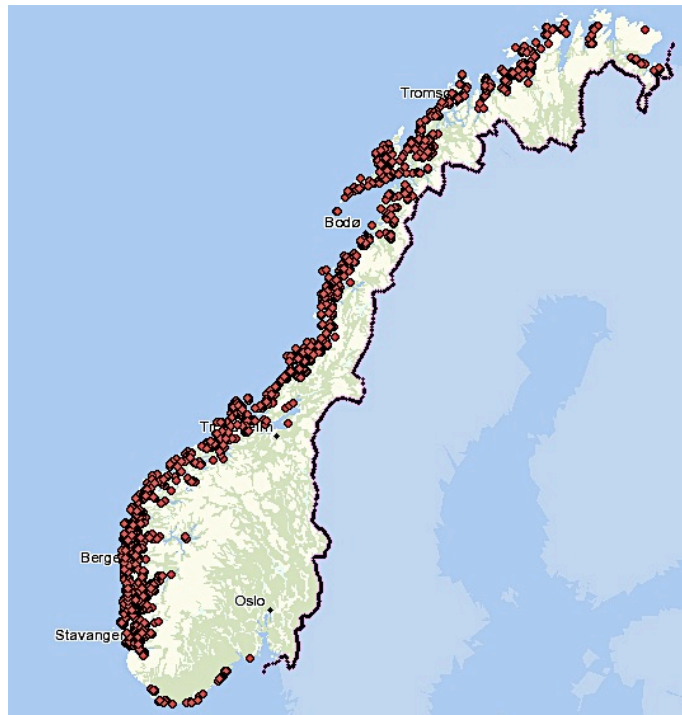


Figure 11: Map of certified ocean based sites. (Photo: Fiskeridirektoratet)

Throughout the last decade the focus on environmental impact of fish farming has increased in Norway, the main challenges being salmon lice and escape from salmon farms. Escape means big economic losses for the farmer and is also a major environmental problem when this fish can go up rivers and reproduce with each other and wild salmon. This can lead to loss of genetic diversity in salmon stocks, as farming harvest has its own genetics, while that of wild salmon is great genetic variation.

Aquaculture and fish farming industry is constantly evolving, and new technologies play an increasingly important role in line with new requirements for more frequent inspections and better documentation from both government and private management. Already in 1997 Lekang wrote in the book *Technology in aquaculture* that: “.. the development has happened so fast that it seems like the instrumentation and automatic monitoring can take over for the fish farmer”. However, Lekang continues by stating that the knowledge about the total picture is inadequate, and it is thus an illusion to believe that fish farming will be completely automatic.

A lot has happened since 1997, and today the situation is quite different, extensive research on marine aquaculture has contributed to increased awareness about the impact fish farming has on the environment. Thus the interest in affordable tools that can conduct investigations of cages and tanks

is increasing, in line with number of restrictions and documentation requirements for sustainable operations.



Figure 12: Merde, marine aquaculture farm. (Photo: Marine Harvest)

Numerous challenges has occurred along with the rapid growth of Norwegian aquaculture production, and environmental concerns have arisen such as fish escape, sea lice and feed- and area scarcity. Five main areas have been identified as areas where the industry may have negative impact on the environment:

- 1) Escaped fish and genetic interaction with wild fish
- 2) Pollution and discharges
- 3) Diseases and parasites
- 4) Use of coastal areas
- 5) Feed resources.

These concerns are still unsolved, thus the industry has improved their control and health routines.

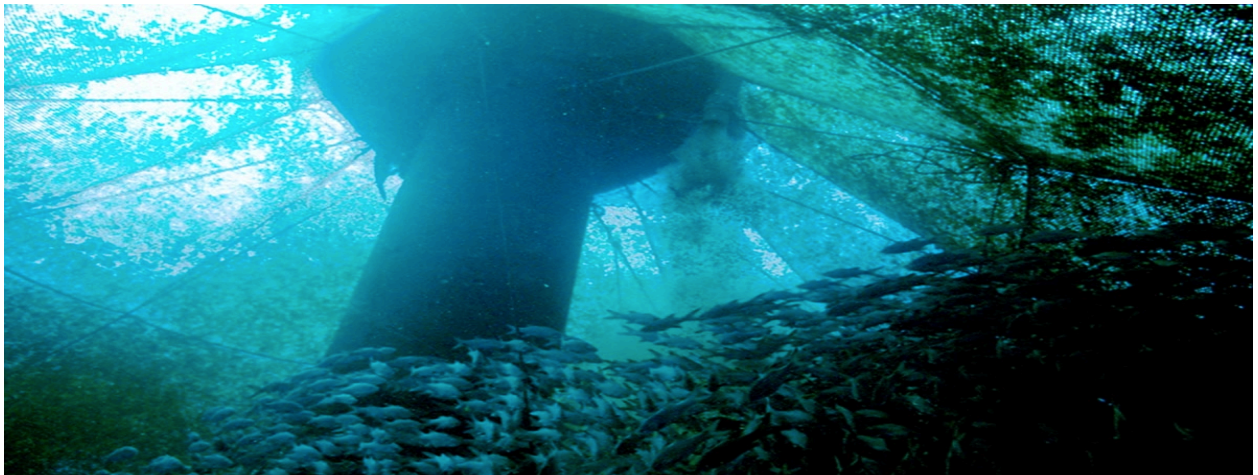


Figure 13: Inside a merde. (Photo: NOAA)

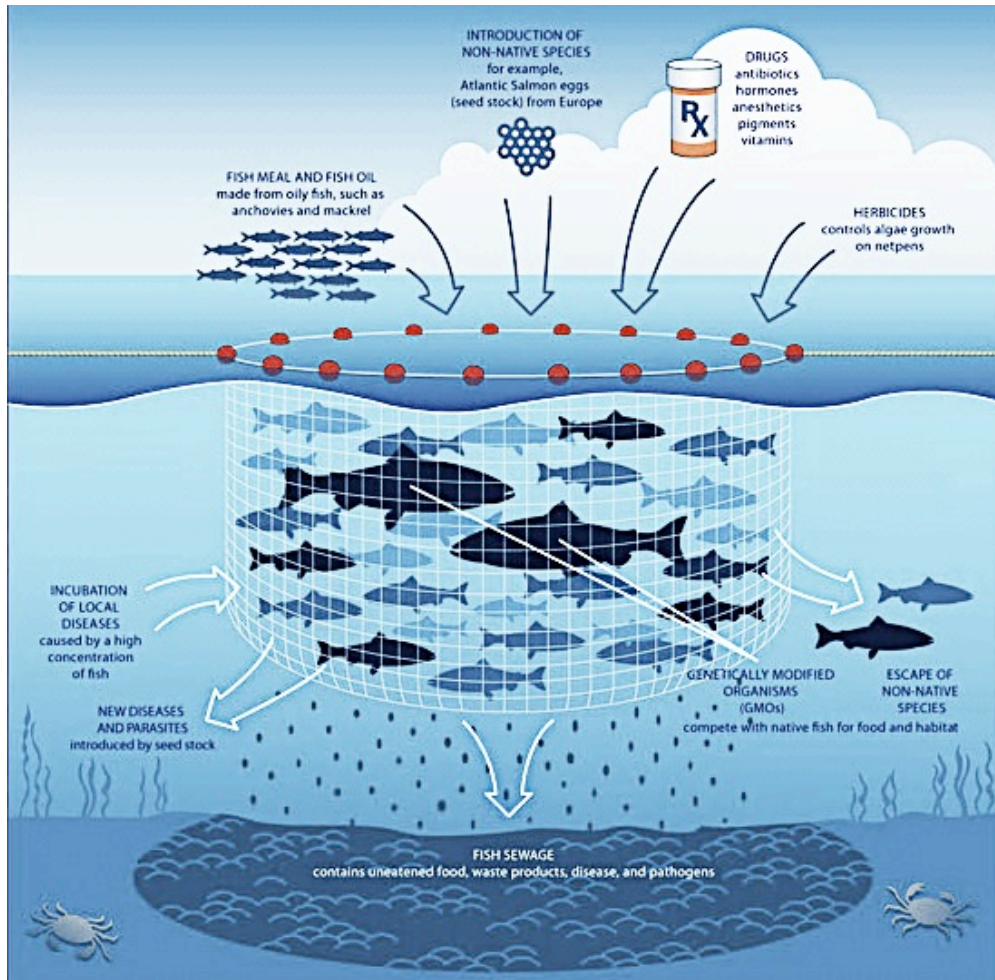


Figure 14: Environmental risks of Marine Aquaculture. (Photo: Dr. George Pararas-Carayannis)

3.3 Safety and rescue service

The Oslo Fire- and Rescue Service is an organization providing an extremely important service, which is to help and save lives of people in emergency situations such as drowning accidents. They also perform search for missing persons, even though hope of finding the missing alive decreases as time pass, it is just as important for relatives that the missing person is found. Thus divers have an important role in the rescue.

Oslo Fire and Rescue Department is one of two stations in Oslo that provide rescue divers with two diving teams and about 30 divers in total. As part of the market survey there has been conducted a "depth interview" with Head of Department of Oslo Rescue Diver Team, Henrik Litland, and 20 divers from the team about the work they perform, procedures, routines and pain points to determine whether a micro-ROV can meet their needs. The interview is presented in chapter 8.

3.4 Various inspection

There are numerous of areas for underwater inspections whereas a small ROV system could serve as an excellent tool.

Examples of areas:

- Hull inspections
- Inspection and exploration in harbours
- Pipes and tanks on subsea installations and power plants
- location of targets under water

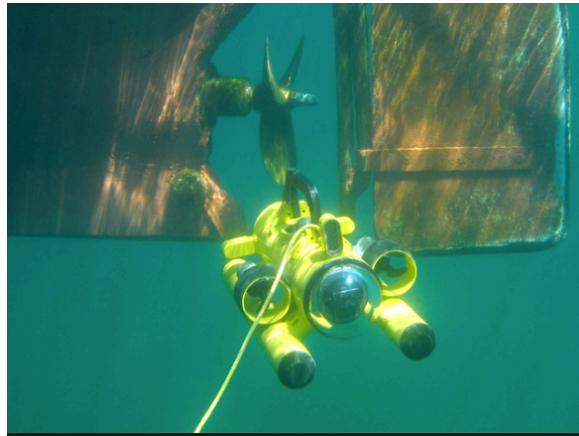


Figure 15: Mini-ROV inspecting propellor and hull. (Photo: Subsea Tech)

4 METHODOLOGY

This study has involved research from traditional textbooks, scientific journals and articles, digital libraries as well as interviews and personal conversations with experts to obtain necessary knowledge on the topics that are presented.

4.1 Terminology

As this study reviews several special fields (robotics, marine biology, underwater monitoring and physics) it is essential to give an explanation on various concepts applied.

4.1.1 Terms and definitions

Table 4: Terms used in this report

Term	Description
Bathymetry	The study of underwater depth of lakes or ocean floors.
Buoyancy	Forces that work in the opposite direction of gravitational forces.
Holonomic	A robot is holonomic if the controllable degrees of freedom are equal to the total degrees of freedom, and it can move instantly in any direction
Tether	Thin cable for signal and data transmission between the control unit and ROV
Turbidity	Coudiness or haziness of a fluid caused by large numbers of particles.

The robot is described by its position and orientation with respect to some reference or observer, most commonly used are *reference frames*. "A reference frame is a collection of points for which the distance between any two points is constant." This reference frame is earth fixed and inertial (From, Pettersen, & Gravdahl, 2014).

Within the reference frame we define a coordinate system:

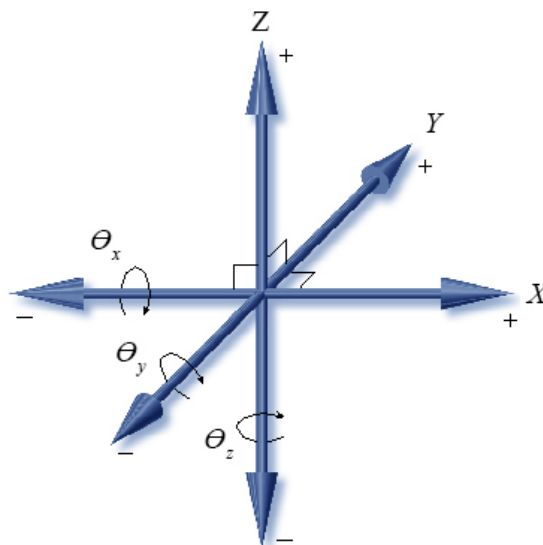


Figure 16: Coordinate system with six degrees of freedom

4.1.2 Symbols and units

Table 5: Symbols and units used in the report

Symbol	Description	Unit (SI)
x	Coordinate, longitudinal direction	m
y	Coordinate, transverse direction	m
z	Coordinate, vertical direction	m
θ_x	Rotation about the x-axis	$^\circ$
θ_y	Rotation about the y-axis	$^\circ$
θ_z	Rotation about the z-axis	$^\circ$
$\dot{\theta}$	Angular speed	m/s
\dot{x}	Speed in x-direction	m/s
\dot{y}	Speed in y-direction	m/s
P_s	Surface pressure	kPa
r	Radius	m
R_t	Turning radius	$^\circ$
h	Hour	s
V	Volume	m^3
D	Drag	N
R_n	Reynolds number	m/s
R	Ideal gas constant	mol
F	Faraday constant	C
T	Temperature	K

4.1.3 Formulas and equations

Some simple formulas are presented early in this thesis to give an explanation on the physical principles that makes up the basis for the robotic systems outlined throughout the thesis.

Table 6: Formulas and equations used in the report

Description	Formula	Index
Pressure	$p = \rho * g * h$	(3)
Vector representation of the motion in the plane	$[\dot{x}, \dot{y}, \dot{\theta}]^T$	(4)

4.2 Research tools and resources

Research within this project has been conducted in several forms, such as reading literature on basic robotics, studies of different ROVs, interviews with representants from the different markets as well as practical surveys and testing.

The thesis is written in Microsoft Word, while tables and diagrams are made in Excel and Adobe InDesign.

SolidWorks has been used to design models for conceptual sensory system to provide a visual description of how such a system potentially may look on the OpenROV.

4.2.1 Literature

This study is based on literature consisting of books, scientific articles and studies. To build knowledge about submarines and submersial conceptuation, those sources are based on recommendations from supervisor, Jan K. Boe and colleagues from OpenROV.

During the study of general robotics in Brazil, the books written by Pål J. From were curriculum and also a natural choice of literature for further studies to understand the dynamic motions of ROVs. The equations and formulas presented in chapter 5 are from these books.

To get necessary knowledge and understanding of coral reefs and marine ecosystems, literature was recommended by Associate Professor in Marine Biology, Ian Bryceson.

In order to gain understanding of technical solutions within the aquaculture industry, the book *Teknologi i akvakulturen* by Associate Professor Odd-Ivar Lekang, has been useful. Even though the book is written in 1997, there are still much of the same principals, and also a lot of the same needs for monitoring, measurements and documentation.

4.2.2 Technical expertise, communication

Throughout the work on this thesis, the author has been privileged to consult experts from various fields. One of them is Product Manager, Zack Johnson, from OpenROV who has been very helpful regarding implementation of sensory systems on the OpenROV (Johnson, 2015). To be able to discuss concepts with him has proven useful due to existing electronics and communication protocol on the ROV, which appeared to be a challenge.

To better understand the essence of environmental monitoring, invaluable input from experts on this field have been assessed and formed the basis for further evaluation and project planning. Professor, Ian Bryceson, has contributed to this thesis with his hands-on experience from investigation of coral reefs with various sensory systems, and by lending sensor equipment to the early surveys conducted in Brazil.

Lars Dalen and Ola Callander have explained how professional divers operate on inspection missions for industries, the challenges they are facing due to depths and documentation procedures.

During the field course in Brazil the author was presented to Tony and Rodrigo, whom are both occupied on a project working with larger ROVs and inspection. To be able to discuss concepts and have their thoughts on sensor implementation on small ROVs have been extremely useful to further work.

Product Manager, Christian Raak, from Miltronic has contributed to this report with valuable information regarding the market situation and details on the VideoRay systems. In same way, Product Manager of Imonic, Åge Baustad, has fulfilled this knowledge by letting the author in on the SeaBotix products.

4.2.3 Surveys and testing

For the surveys that have been performed during this project there have been used three ROVs from OpenROV, whereas one of them is the 2.6 model and the two others are of the latest version 2.7.

In the surveys performed in Brazil, a sensory system from YSI were used and mounted on the ROV.

4.3 Process diagram

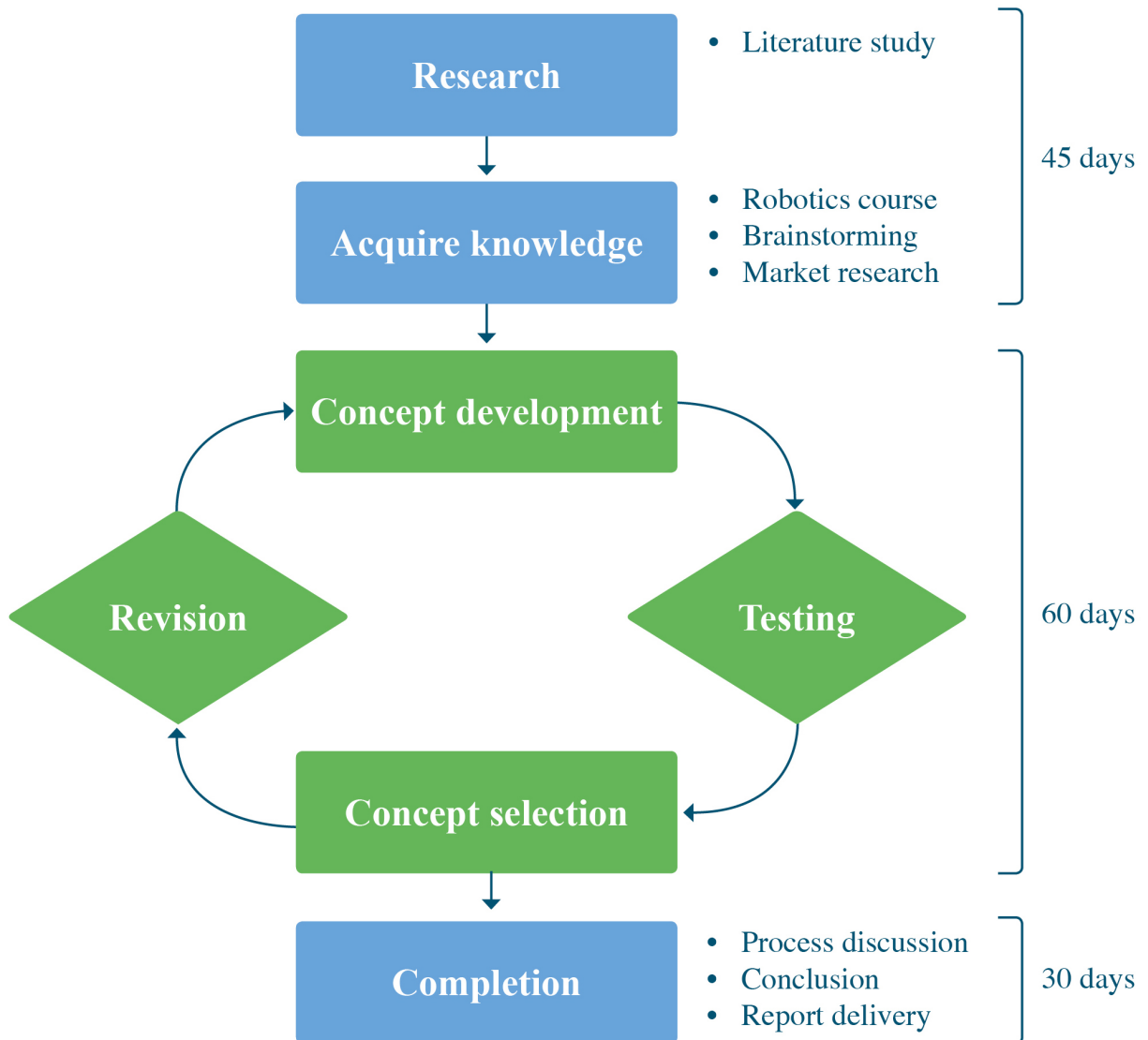


Figure 17: Steps throughout this project with time limits

5 BASIC THEORY

In order to develop the ROV sensory system, there is some basic theory that needs to be explained. This chapter presents the dynamic equations and laws that describes the motions and operational room of the ROV, and outlines physical constraints.

5.1 Physics

Pressure

Pressure is a force that plays an important role when designing underwater constructions, the deeper you go, the more challenging it is. At surface level, the atmospheric pressure is around 100 kPa, and about 10 meters below surface the pressure is doubled (~200 kPa). This cause challenges when operating with air-filled cases and components, for example the electronic tube on the OpenROV, because the air will reduce in volume in line with increasing pressure and may cause implotion.

The hydrostatic pressure equation is given by:

$$p = \rho gh \quad (3)$$

where p is the pressure exerted by a column of liquid of height h and density ρ .

Dynamics

The dynamics of underwater robots are complex because of the various terms that arise due to the underwater environments. In addition to the rigid body properties, there are several important effects that need to be included to obtain a complete and accurate description of the dynamics of underwater vehicles. In the setting of this paper it is important to note that adding sensory systems to the robot will affect one or more of the terms that arise in the dynamics.

The ROV is underactuated which means that it has a lower number of actuators (3 thrusters) than degrees of freedom (6DoF). We derive the dynamic equations of underwater robots. In addition to the standard terms found in rigid body motion, additional terms in the dynamic equations arise due to the hydrodynamic effects that occur when a rigid body is submerged in water. The main contributions of the hydrodynamic forces and moments are added mass, radiation-induced potential damping, and restoring forces (Faltinsen, 1990).

We will attach a frame \mathcal{F}_b to the vehicle and denote the location of \mathcal{F}_b with respect to the inertial frame \mathcal{F}_0 by the homogeneous matrix g_{0b} and its velocity by the body velocity twist $\hat{V}_{0b}^B = g_{0b}^{-1} \dot{g}_{0b}(q)$ (From, Pettersen, & Gravdahl, 2014). As both the ROV actuators and the camera actuators affect the robot in body coordinates, we will use body velocities to describe the robotic motion, i.e.;

$$V_{0b}^B = \begin{bmatrix} u \\ v \\ w \\ p \\ q \\ r \end{bmatrix} \quad (4)$$

Each of these velocities corresponds to a direction, also defined in the body coordinates of the ROV, given by the vector;

$$\begin{bmatrix} x \\ y \\ z \\ \phi \\ \theta \\ \psi \end{bmatrix} \quad (5)$$

The dynamic equations of a completely or partially submerged rigid body is written as [Fossen, 2002, From et al., 2014];

$$\dot{\eta} = J(\eta) v \quad (6)$$

which can be written as

$$\underbrace{M_{RB}\dot{v} + C_{RB}(v)v}_{\text{Rigid body}} + \underbrace{M_A\dot{v} + C_A(v)v}_{\text{Added Mass}} + \underbrace{D(v)v}_{\text{Potential damping}} + \underbrace{N_g(\eta) + N_b(\eta)}_{\text{Restoring forces}} = \underbrace{B_u}_{\text{Actuation}} \quad (7)$$

where $\eta = [x_{0b} \ y_{0b} \ z_{0b} \ \phi \ \theta \ \psi]^T$ is the position and orientation of the ROV given in the inertial frame and $v = [u \ v \ w \ p \ q \ r]^T$ is the linear and angular velocities given in the body frame. M_{RB} and C_{RB} are the inertia matrix and the Coriolis matrix of the system, M_A and C_A are the added mass inertia and coriolis matrices, D represents the damping terms and N_g and N_b the potential forces (gravity and buoyancy, respectively) of the system. The actuator forces (control) are represented by u and the actuator transformation matrix B .

The first terms correspond to the rigid body dynamics that we find from Newton's second law. These are independent of the environment in which the rigid body operates and are found in the same way for all types of mechanical systems. The added mass terms appear as a result of the robot being submerged in water, as well does the damping and restoring forces. Note that all these matrices change if a sensor with non-negligible mass or volume is added to the ROV. Sensors with large masses, can drastically change the dynamic characteristics of the ROV (From, Pettersen, & Gravdahl, 2014).

Sensor theory

In the practical part of this project testings with sensor systems are performed, and thus it is vital to outline the principles behind the sensor technology. The sensors that have been used are measuring pH and dissolved oxygen.

The oxygen sensor is made up of a positively charged wire (anode) and a negatively charged wire (cathode) separated by an insulator. Around the anode and the cathode is an electrolyte held in place by a cap. Inside this cap is a membrane, made so that the oxygen molecules in the water can pass through. Between the electrodes there is an electrolysis, and the amount of oxygen molecules are transported through the membrane, is an expression of the amount of oxygen the liquid contains.

A pH instrument is in principle designed in the same way as the oxygen sensor, made up of two electrodes, a pH electrode and a reference electrode. The pH electrode is made of glass, sheathed by a membrane that H^+ ions can pass through. Inside the chamber the membrane surrounds, sits an electrolyte. The voltage between the pH electrode and the reference electrode is measured. The more H^+ found in the liquid, the more power will go between electrodes. (Lekang & Fjæra, 1997)

The probe measures pH by the current that is generated from the hydrogen ion activity which is the reciprocal activity and that can be predicted using this simple equation:

$$E = E^0 + \frac{RT}{F} \ln(\alpha_{H^+}) = E^0 - \frac{2.303RT}{F} pH \quad (8)$$

where R is the ideal gas constant, T is the temperature in Kelvin and F is the Faraday constant.

Hydrodynamic

Drag forces are forces that act between the water and the ROV and increases due to friction. The design and shape of the ROV determines movements, how fast it can go and stability and thus these forces have to be taken into account when

$$F_D = -\frac{1}{2} \rho C_D (R_n) A |u|u \quad (9)$$

Where u is the vehicle velocity in one of the main directions, A is the area of the component, ρ the water density and C_D the drag coefficient. The drag coefficient is a function of the Reynolds number given by the following equation:

$$R_n = \frac{UD}{\nu} \quad (10)$$

Where U is the body velocity, D the characteristic length and ν the water viscosity.

Applied theory in the OpenROV concept

More technically specific, the OpenROV has three actuators; two horizontal thrusters to move it forward and rotate it, and one vertical thruster. The ROV has 6-DoF, however it has only three actuators which makes it an underactuated system with relatively good maneuverability. The system is a non-holonomic system. The ROV has three degrees of freedom linear motion and one degree of freedom rotational motion.

6 EVALUATION OF CURRENT TECHNOLOGIES

As mentioned in the introduction of this report, there are several existing concepts for underwater monitoring and inspection used in multiple applications. In this chapter three concepts are presented and compared to the OpenROV, and hence outline potential advantages and disadvantages, potentials and challenges with the different systems.

6.1 Robotics

Definition

"A robot is a versatile mechanical device - for example, a manipulator arm, a multi joint multi fingered hand, a wheeled or legged vehicle, a free flying platform, or a combination of these - equipped with actuators and sensors under the control of a computing system. It operates in a workspace within the real world. This workspace is populated by physical objects and is subject to the laws of nature. The robot performs task by executing motions in the workspace."(Latombe, 1991)

Classification

Classification of mobile robots is done by their ability to move freely around in their environment, and they distinguish from conventional industrial robots by their possibility to locomote within a given environment, and also possibly between different environments (From, Pettersen, & Gravdahl, 2014).

A robot can be described as an electro mechanical system. This system is connected to a regulator and one or multiple actuator(s), and normally has one or more sensors. The sensors can be classified as internal and external. The internal sensor is usually sensing position and movements, whereas the external sensors can vary from the parameters the robot is constructed to measure, e.j. visual, temperature etc.

ROV

The main motivations for remotely operated underwater robots is to relieve humans from entering hostile and dangerous underwater environments and to utilize robots for continuous operations that are too time consuming to be performed by humans.

Application examples: Aquaculture, film, marine life observation, pipe inspection, science and oceanographic research, ship and propeller inspection, search and rescue works, nuclear power stations, Subsea constructions and maintenance, coast guard.

Underwater vehicles are separated into two basic categories; manned and unmanned vehicles, often called AUVs and ROVs. AUVs are autonomous underwater vehicles, which means they are free from tether and can run on either a preprogrammed or logic-driven course. Remotely Operated

Vehicles (ROVs) are connected to the surface for communication and/or power by direct hardware (Figure 16).

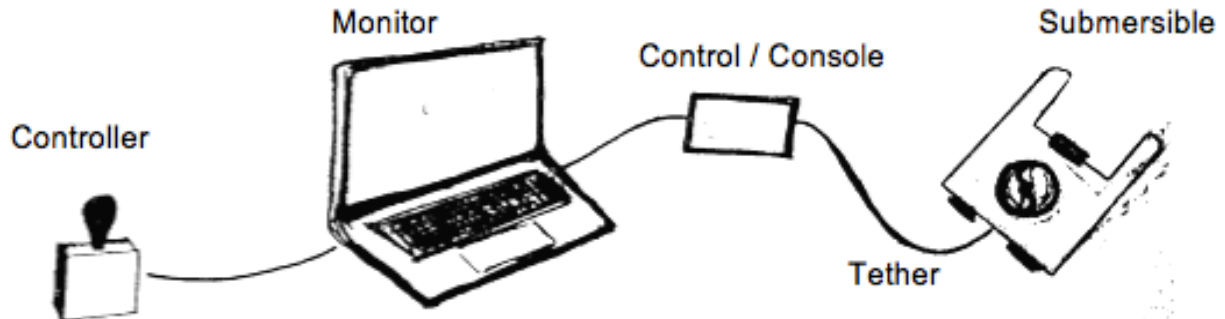


Figure 18: ROV communication system.

These are further segmented into four categories based upon size and capabilities;

- 1) Observation class ROVs which are the smallest micro-ROVs that weigh up to 100 kg and have a depth range up to 300 m
- 2) Mid-sized ROVs that weigh from 100 kg up to 1000 kg
- 3) Work class ROVs
- 4) Special-use ROVs

The motion of the vehicle is depending upon the vehicle's capability and the operator's degree of input, and can either be via autonomous logic direction or remotely controlled by the operator.

6.2 Overview of ROVs used today

There are multiple small sized ROVs that today are intended for inspection of any underwater objects such as wrecks, ship underwater parts, propellers and different underwater constructions. In the work on this thesis, the following systems are investigated:

- SeaBotix LBV150-4
- GNOM ROV
- VideoRay Pro 4

Those are existing micro-ROVs in the market that, due to size and features, have been compared to the OpenROV. In short, the advantages are that they are more robust and more complex, and the disadvantage is the price.

6.2.1 VideoRay Pro 4

VideoRay is one of the largest manufacturers of small ROVs, with more than 2500 sold systems. The VideoRay Pro 4 (see Figure 19) is their most sold model and has proven very beneficial on several instances, such as the Costa Concordia wreck removal project that began in 2012, where this ROV was recording 45 000 hours of video. This project is one of the largest missions by observation class ROVs in history.

Since 2007, VideoRay has been provided to the Norwegian market by Miltronic, who has delivered over 100 systems to customers within the offshore industry, professional divers, hull inspection and marine aquaculture(VideoRay). According to Miltronic's Product Manager of VideoRay, Christian Raak, the market for mini-ROVs is increasing (Raak, 2015). The VideoRay Pro 4 is still a product best suited to the industrial market due to the high price level. The more basic systems provided by VideoRay are two simpler systems called Explorer and Scout, whereas the most affordable, Scout, has a price tag around \$9.000 USD, while the advanced Pro 4 system cost up to \$270.000 USD.



Figure 19: VideoRay Pro 4. (Photo: VideoRay)

6.2.2 GNOM Standard

The GNOM ROVs were developed in Shirshov Institute of Oceanology at the Russian Academy of Sciences. The GNOM manufacturer provides several micro and mini-ROVs that are known for their thin tether and the solution on magnetically coupled thrusters that require less maintenance. The GNOM standard is the model that is the highest grossing product.



Figure 20: GNOM Standard. (Photo: GNOM)

6.2.3 Seabotix LBV 150-4

Seabotix is a US based company manufacturing multiple ROV systems whereas the LBV 150-4 is the smallest one.

Imenco is the Scandinavian distributor for the LBV series, whereas the SeaBotix LBV 150-4 is the smallest model suited to onshore or civil applications according to Imenco's homepage. Here, they claim that they have sold dozens of mini/observation ROVs to clients for observations, inspections, surveillance of diving operations and fish farming inspection.



Figure 21: SeaBotix LBV 150-4 (photo: Imenco)

Seabotix is considered to be VideoRay's biggest competitor on the Norwegian market.

Compared to these three existing concepts, the OpenROV is much more to consider as a tool for exploration and educational purposes. None of the forementioned can compare to the OpenROV on price, but on the other hand, the OpenROV is not nearly as reliable and robust as the other ROVs – however if assembled by professionals it goes just as deep as the GNOM and it is by far the easiest to handle due to weight and size because this is the only system where the total system fits in one pelican case, and does not require an external control unit except your own personal computer.

It is important to separate the OpenROV kit from the fully assembled. A customer who purchase a kit and assemble the ROV system himself, has no guarantee that it is i.e. waterproof. There are multiple possible weaknesses that can occur during welding, gluing, potting av end-caps and so on.

According to General Manager at Marint Forum, Erik Dyrkoren, thruster power is one of the main requirements with large potential for improvement within existing concepts. In the Aquaculture, for instance, the sites are often located in areas with strong currents and thus the ROV needs to be able to hold constant horizontal speed to provide video documentation of sufficient quality.

Table 7, gives an overview of specifications for the forementioned ROV systems; the GNOM Standard, VideoRay Pro 4, SeaBotix LBV 150-4 and the fully assembled OpenROV v2.7. All of the prices of the systems presented are the basic solutions with no extra features included.

Table 7: Specifications of the VideoRay Explorer, GNOM Standard, Observer 3.2 and OpenROV v2.7

Specks \ ROVs	GNOM Standard	VideoRay Pro 4	SeaBotix LBV 150-4	OpenROV v2.7
Dimensions [cm]	35,0 x 20,0 x 20,0	37,5 x 28,9 x 22,3	53,0 x 24,5 x 25,4	30,0 x 20,0 x 15,0
Max Horizontal Speed	2 knots	1,9 knots	3 knots	3 knots
Weight [kg]	3 kg	6,1 kg	11 kg	2,6 kg
Thruster technology	24 VDC brushless	DC brushless	DC brushless	DC brushless
Thrusters	3	3	4	3
Power supply	Surface power supply	Surface power supply	Surface power supply	Rechargeable lithium batteries
Running time	- no limit	- no limit	- no limit	3-4 hours
Price	\$ 9.000	\$ 47.000	\$ 40.000	\$ 1.499
Sensors	Compass heading, Depth gauge	Compas heading, Depth gauge	Heading, depth, temperature	Compass heading, depth guage, temperature
Camera system	Sony Super HAD 2CCD, 600 TV lines, 0,1 lux, tilt function	Colour camera, 570 lines of resolution, 0.3 lux (NTSC or PAL), tilt function	680 line Wide Dynamic Range color – 0.1 lux	HD Webcam (120 deg FOV) with audio
Max depth	150 m	250 m	200 m	100 m
Control system	Surface control unit with joystick	Integrated Joystick and depth control, Auto depth	4 axis intuitive control	Controlled from personal computer, OpenROV programme
Lights	<ul style="list-style-type: none"> • White ultra-bright LEDs • Variable intensity 	<ul style="list-style-type: none"> • 20w Halogen Lamps • Variable Intensity Control 	<ul style="list-style-type: none"> • 700 Lumen LED array • Variable intensity 	<ul style="list-style-type: none"> • White ultra-bright LED lights
Monitor	15" colour LCD	7" colour LCD Panel Display	15" color LCD	Personal computer
Tether	250 m, 4 mm	40 m, 8 mm	150 m, 9 mm d	100 m
Additional options	<ul style="list-style-type: none"> • Flexible tether • Laser Scaling • Grabber 	<ul style="list-style-type: none"> • Sonar • Sampler • Navigation • Automatic search function • Positioning system 	<ul style="list-style-type: none"> • Grabber • External LED lights • Zoom camera • Tether management system 	<ul style="list-style-type: none"> • Open-source design & software • 6 extra auxiliary wires for additional add-ons

The dynamics of underwater robots is complex due to the various terms that arise based on the underwater environments. In addition to the rigid body properties, there are several important effects that need to be included to obtain a complete and accurate description of the dynamics of underwater vehicles. In the setting of this paper it is important to note that adding sensory systems to the robot will affect one or more of the terms that arise in the dynamics.

It is very different to work in an underwater environment than traditional operation on dry land, and there are many challenges that need to be overcome when we introduce robotic systems to work underwater, because they are usually electrically or hydraulically driven and such systems need to be waterproof and cope with pressure forces.

Buoyancy forces tend to lift the object towards the surface and thus work in the opposite direction of gravitational forces. If the center of gravity and buoyancy forces are aligned, it is a linear force that either reduces the effects of the g-forces and slows down the falling motion, or it lifts the object towards the surface.

If the density of the water is equal to the object, we say that the object is neutrally buoyant, as if no g-forces were present.

Remotely Operated Vehicles (ROVs) are underwater vehicles physically linked by a tether to an operator that can be based onboard a boat or onshore. Communication from the ROV as well as power supply is given via the tether. Furthermore ROVs may be equipped by sensor systems and manipulators for various purposes.

6.4 OpenROV

The OpenROV is a micro-ROV based on open source technology. This means that development and improvements of the product is happening fast. In fact, there are more than 500 developers from about 50 countries who have contributed along the way.

To measure depth, the OpenROV is equipped with a depth sensor with two principle devices on it; a 9-axis IMU and a pressure sensor, both connected to one PCB and attached to a single I2C line. This is important to understand, because this is where additional sensors may be attached to communicate through the I2C line to the Arduino and provide data to the computer. More details will be presented later in this chapter.

It is equipped with a high-definition camera with tilt-function that sends live video via a cable to a personal computer. The camera has a controlled tilt of +/-60 degrees from center, and the HD live video is up to 1080p with wide angle lens. This cable can be up to 300 meter long and the ROV can go down to 100 meters depth. The communication protocol used is IEEE 1901, also called Homeplug AV, allowing the operator to give commands through the haptic manipulator from the ROV via Ethernet to personal computer presented in the OpenROV Cockpit program. In addition to the camera, the ROV has an IMU (Inertial Measurement Unit) with a pressure sensor and compass to measure depth and heading. On each side of the camera the ROV has white LED-lights with <200 lm and red lasers providing a distance reference with possibility to measure length of objects in the camera view.



Figure 22: OpenROV v.2.7 (Photo: OpenROV)

The ROV can be carried in a practical pelican case or even a backpack, and is therefore easy to bring on-board any boat. The robot is easy to set up and normally ready to use within 2-3 minutes.

Another advantage of the OpenROV is that it is extremely easy to operate. It can be set up by using a personal computer in a very short time and no expertise on robotics or knowledge on how to operate these is required. The robot is also available as a kit and can thus be customized for a wide variety of uses in a very short time. The OpenROV costs less than US\$1000.

The ROV has six additional auxiliary wires for user-defined external instrumentation or devices, which may be used for attaching sensors or other equipment. This opens for attaching the necessary sensory systems for environmental monitoring to the robot, and communication with these.

6.6 Sensory systems for OpenROV

Different types of sensory systems are provided from several suppliers and weights from about 250 grams to 500 grams. Because the ROV itself weights only 2,7 kilograms, the additional weight will affect the maneuverability of the system, and it is therefore important to consider both weight and shape when choosing such system. For example, during tests with sensors weighing 400 grams performed in both fresh and salt water, in order to see if the impacts on the dynamics were acceptable, we found that there were no dramatic effects on the maneuverability of the robot as long as the sensor is attached below the center of mass of the robot.

As mentioned above, coral reefs are highly sensitive to changes in external conditions like pH and temperature. That is why these are important parameters to monitor around the reefs, thus changes may cause stress and dying reefs.

There are multiple sensors for monitoring these factors. Sensing pH values are done by measuring the concentration of hydrogen ions by electrodes. Such sensors are often small probes in the size equivalent to a short pencil and weight around 50 grams; the same size as of the probes measuring

oxygen and temperature. Turbidity sensors measures suspended solids in the water by optics, and is normally slightly larger in size than the other probes and weigh approximately 150 grams.

The main objective of this thesis has been to propose a solution to environmental monitoring using appropriate sensory systems. In addition to maintaining the cost low, we need to make sure that the maneuverability of the ROV is maintained, which can often be a problem as these sensors are often heavy and large.

The gravitational effects of adding sensors can to a certain extent be compensated for by adding and removing mass to the robot. However, some of the sensors such as the YSI 556MPS described below, are heavier than the available removable weight, which results in a rather large energy consumption as the buoyancy needs to be compensated for by active actuation. This can reduce the operation time of the robot substantially.

6.7 Uncertainties and challenges

Micro-ROVs are small and lightweight compared to the bigger industrial ROVs that are most commonly used on subsea installations. The ROV has to cope with several challenges while operating underwater. Some of these challenges are mentioned earlier. Furthermore the salinity level in the water can cause corrosion. Salt water in combination with electric voltages speed up the corrosion process, which can change the kinematic and dynamic properties of the ROV. The salt makes the water into a good conductor which increases the danger of short-circuits. Thus it is important to protect all electronics against water and water vapor. In addition, if corrosion occurs over longer periods of time this can eventually cause the ROV to break down mechanically.

The mechanical design relies on these forces and the challenge is to determine the optimal configuration. Furthermore communication and localization present additional challenging areas. GPS signals are not powerful enough and does not transmit very well in water. Therefore a GPS requires a direct line-of-sight between the transmitter and the receiver, and hence does not work in an underwater environment.

There is, however, several projects with ongoing research on acoustic positioning systems at OpenROV headquarter in Berkeley, California, which is expected to show results within the near future.

7 EARLY COMPONENT TESTING

Within this thesis, implementation of sensors has been tested in order to determine whether OpenROV will meet the needs and provide as a useful tool for monitoring water qualities and thus be a potentially attractive product for assisting marine biologists and the aquaculture industries.

7.1 Testing of sensory systems on OpenROV

There are several parameters in the cases mentioned above that would be valuable to measure, such as pH, ORP, conductivity, dissolved oxygen and turbidity. However, this project has focus on pH measurement, mainly because that is a useful parameter to monitor both for the aquaculture industry and marine biologists for environmental monitoring.



Figure 23: pH probe. (Photo: Atlas Scientific)



Figure 24: Dissolved Oxygen probe. (Photo: Atlas Scientific)

The pH-probe used in the testing is a single sensor provided by Atlas Scientific (see Figure 23), and is 15 cm long and 1,2 cm wide, and only weights about 100 grams. The size and weight of the sensors are important, and so is the speed of response which is in 1 second.

The aim for this test is to develop a system such that it is possible to read the measurements from the sensor parrallell to the video in the OpenROV cockpit. In order to get the values from the sensor "live" to a computer, the sensor needs to be connected to an Arduino Uno, to communicate through the BeagleBone and then via the tether to the top-side adapter that transfer data to a personal computer.

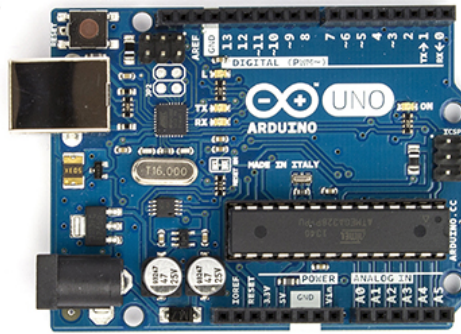


Figure 25: Arduino Uno microcontroller board. (Photo: Arduino.cc)

7.1.1 Testing 1 – Ultimate Controller

This test is a result from research of possible systems to implement on the OpenROV v2.7 to make it a useful tool for environmental monitoring and measurement of water qualities. Search for existing solutions for sensory systems led to the Arduarium Ultimate Controller (AUC), a shield with BNC connectors that makes it possible to connect the pH probe to Arduino.

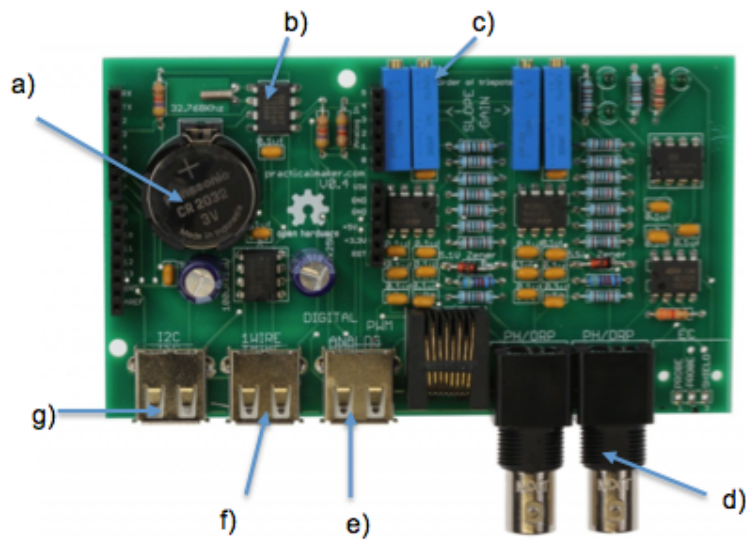


Figure 26: Arduarium Controller Ultimate with a) CR2030 3V lithium battery, b) DS1307 Real-time clock, c) trim pots to adjust pH and ORP, d) 2x female BNC connectors, e) Analog USB hookup, f) 1wire USB hookup, g) I2C USB hookup (Photo: Proto-PIC.co.uk)

7.1.2 Testing 2 – EZO pH circuit

Testing 2 endeavoured to build a sensory system consisting of EZO circuit carrier board with the ability to measure pH and Dissolved oxygen, using different EZO circuits for each parameter.

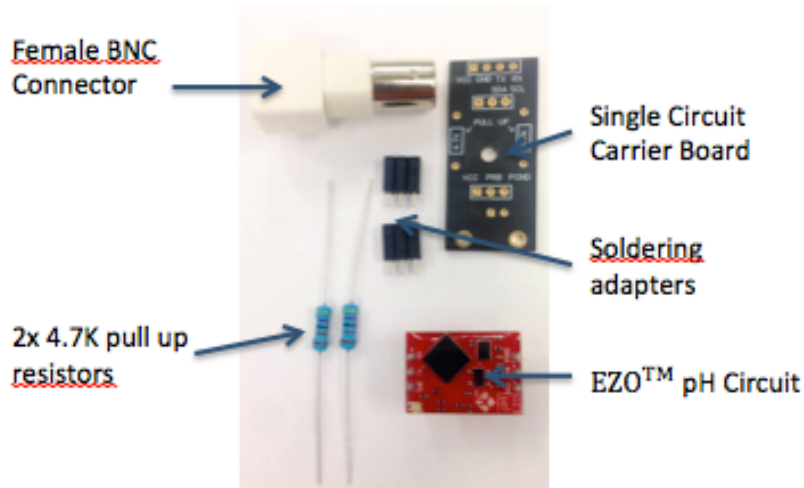


Figure 27: Components used in Testing 2, from Atlas Scientific. (Photo: Spiten)

To assemble the components requires some soldering on the carrier board. After the BNC Connector, resistors and adapters were soldered onto the single circuit carrier board, the EZO pH circuit can be connected on top of the adapters without any soldering, and is thus easy to remove.

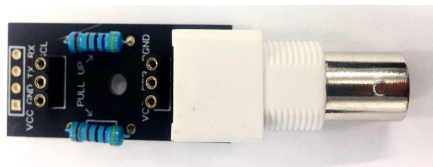


Figure 28-a: Female BNC mounted on circuit board. (Photo: Spiten)



Figure 28-b: Complete assembled. (Photo: Spiten)

To receive meaningful measurements of pH, the probe needs to be calibrated due to three specific pH values (4, 7 and 10).

7.2 System implementation

When implementation of the sensory system to the OpenROV there are certain aspects to consider:

- Design
- Size
- Weight
- Removability
- Communication
- Waterproof cases and connections

The carrier boards goes on top of the Arduino Uno, and the female BNC connectors is connected to the probes. In the part of *Testing 2* there is proposed a conceptual model for mounting solution and housing of both sensor probes on the base of the OpenROV v2.7. The objective of this model was to minimize the size and weight in order to avoid interference onto the ROV's driving

characteristics as much as possible. Thus it was two main goals that should be adhered to in the model;

1. Waterproof housing for circuit boards and Arduino Uno, with tight openings for wires leading from the sensors to the BNC connector, and the wire from the Arduino up to the I2C.
2. A lightweight yet protective rail for the sensors so that the probes are exposed to direct water flow, while at the same time being protected to the greatest possible extent against shocks.

Design proposal

Based on the sensory system from Testing 2, the following design is proposed for implementation on the OpenROV. The drafts are made in SolidWorks and presented in the figures below from two points of view.

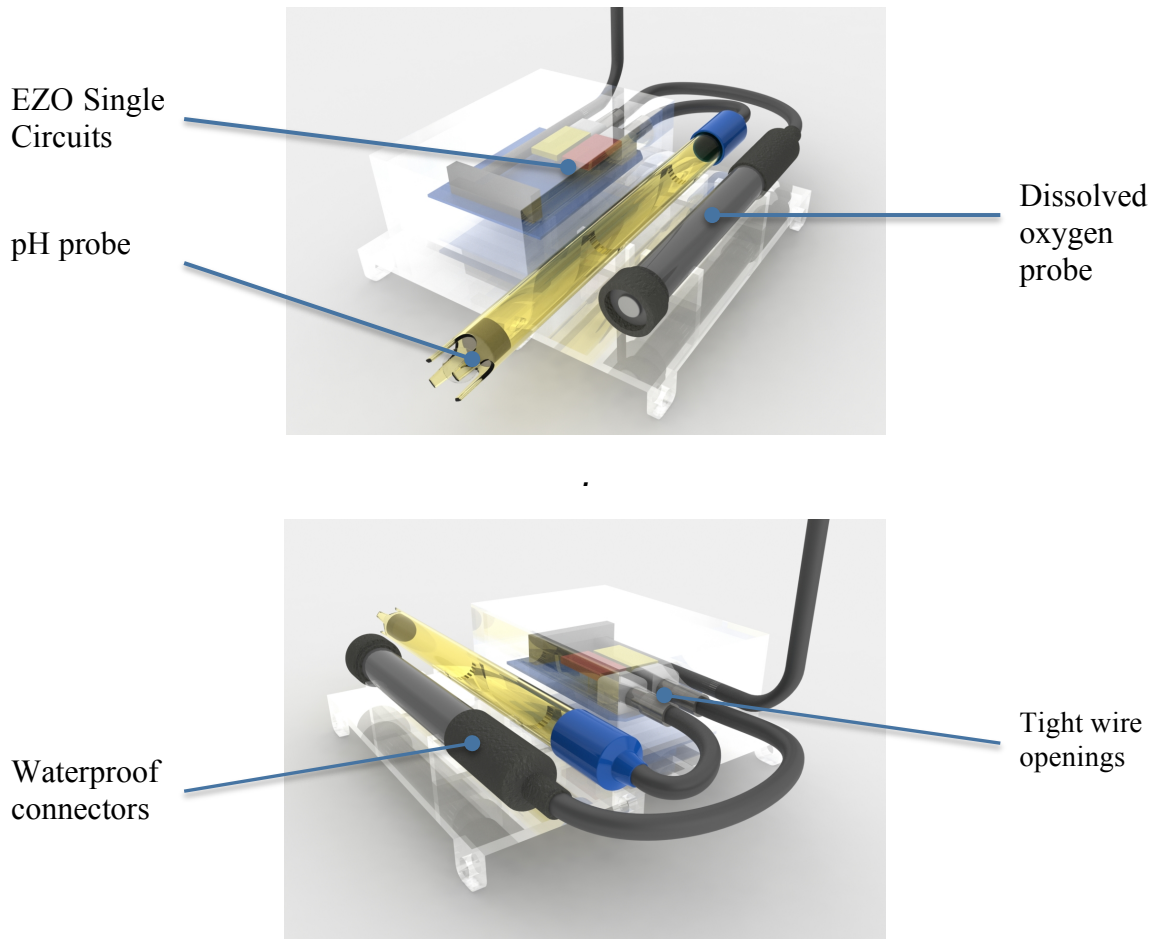


Figure 29: Conceptual design of housing for circuits and Arduino. (Illustrations: SolidWorks)

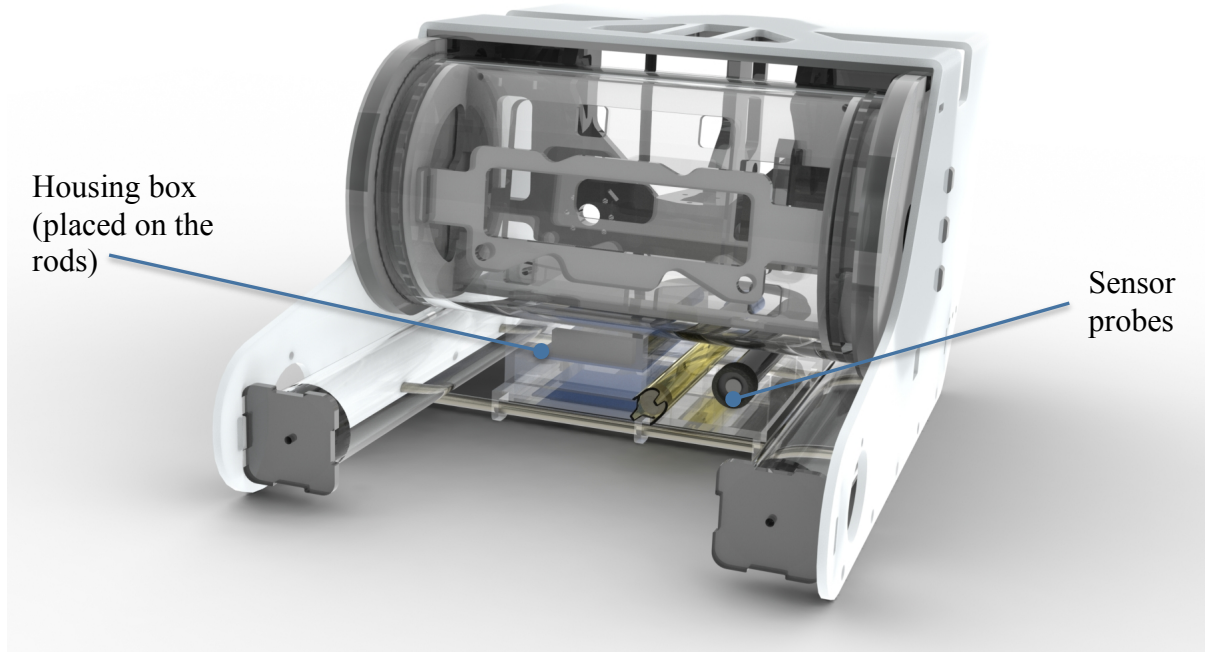


Figure 30: OpenROV v2.7 with suggested sensory system mounted below the electronics tube. (Illustration: SolidWorks)

In the figure above it is shown how the system is placed on the rods on the base of the OpenROV. Without any other changes on the design, this is assumed to be the best way to place the system on the v2.7.

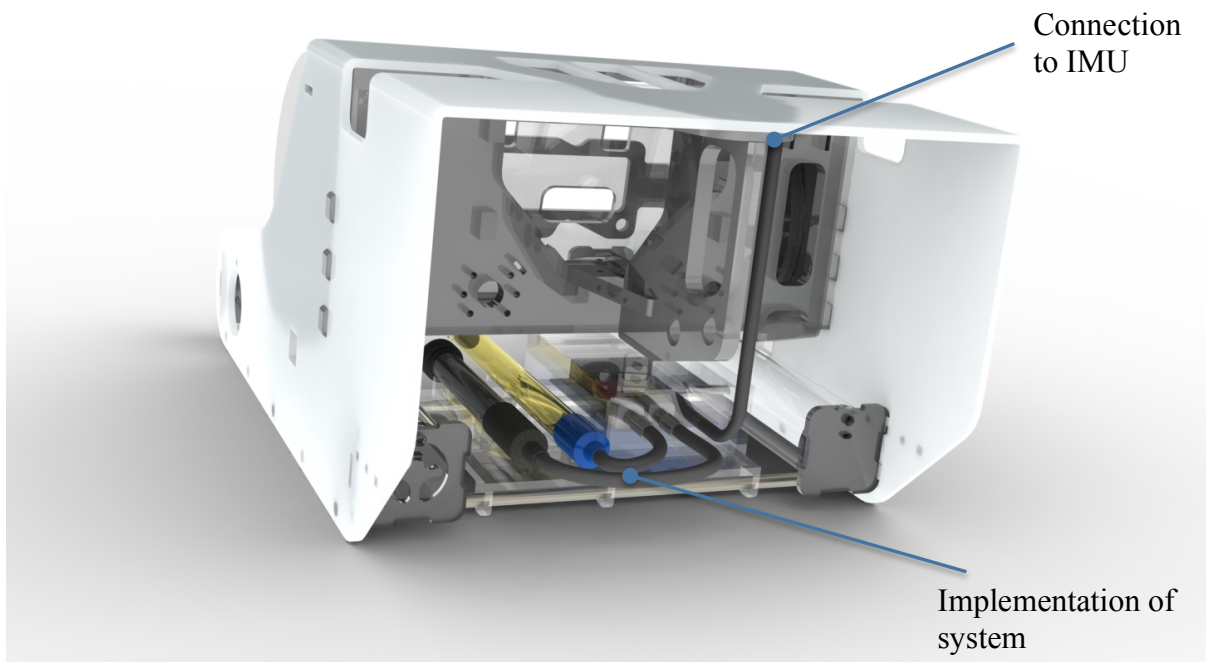


Figure 31: Sensory system from behind. (Illustration: SolidWorks)

8 FEASIBILITY AND MARKET RESEARCH

As part of this thesis, possible needs in the market are investigated. Research of three different sectors have been conducted, and this chapter presents the research model and research plan, and furthermore reveals details and key findings from the process.

8.1 Research model

Research of the market has been done to uncover possible needs and end users of micro-ROVs. To divide the market into an industrial and consumer market has been the first step to separate very different willingness to pay between those two. Furthermore the focus within the industrial market has been on the three from previous chapters; environmental monitoring, aquaculture and rescue service. The research is based on different hypothesis for each market and industry, thus questions either confirm or deny these hypothesis.

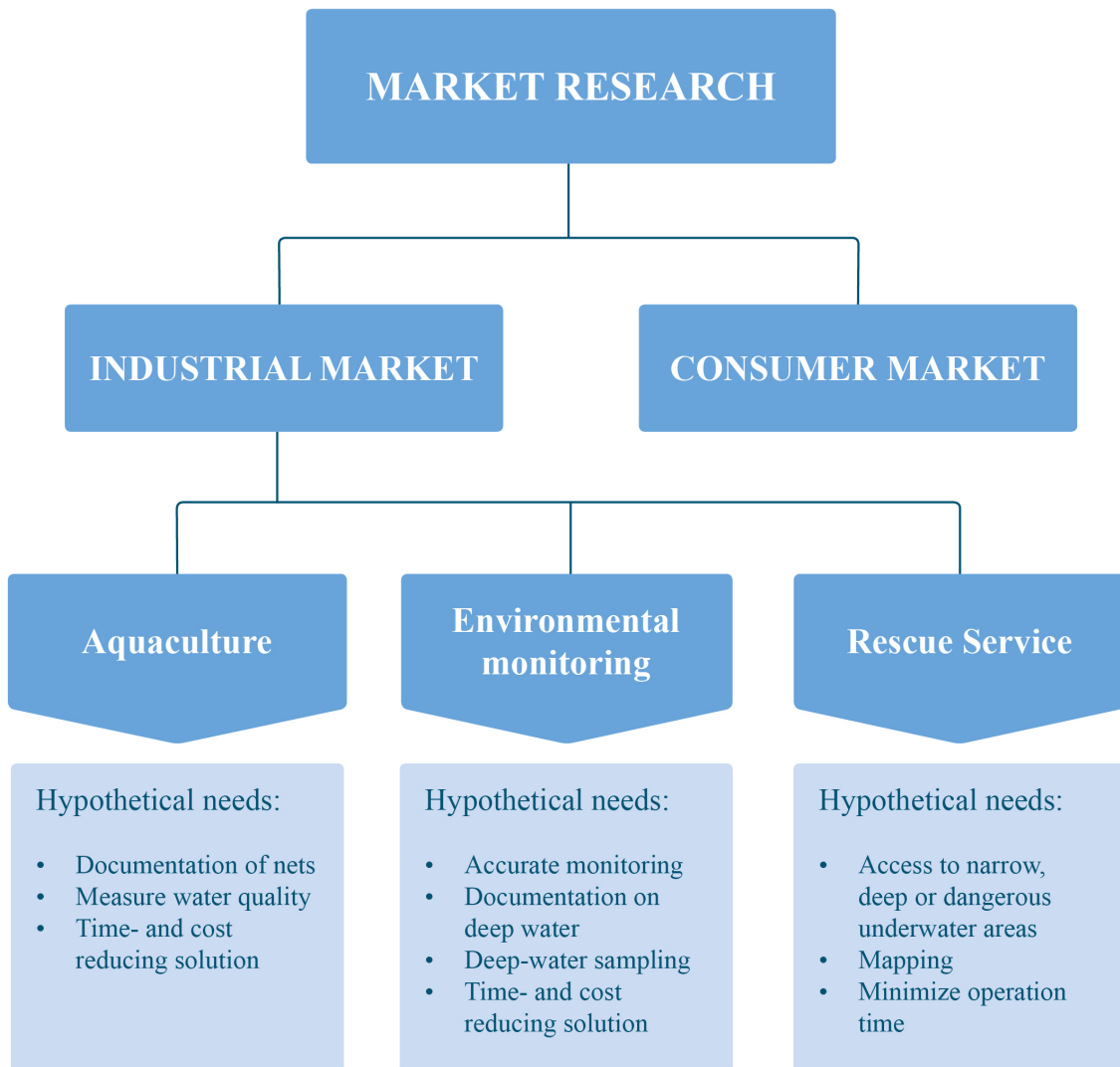


Figure 32: Overview of market segmentation. (Illustration: Spiten)

The hypothetical needs outlined in Figure 32 are the needs that the author assumed existed in each industry based on literature. Each of them are investigated further through conversations and interviews with representatives from the forementioned industries.

The results and findings are thus used to form the base for a business plan described briefly in chapter 9.

8.2 Environmental monitoring

To uncover the needs for environmental monitoring, several methods have been used. The natural choice of experts to talk to was marine biologists and scuba divers. Marine biologists are scientists that often spend a lot of time in the coastal environment and perform hands-on research on site. They obtain great knowledge of the marine environment and have experienced the change of conditions whereas some of them still remains as unanswered questions.

Experts

During this project there is one person that has been very supportive and shared of his knowledge on the marine environment and who also had valuable experience of monitoring equipment and usage. Associate Professor by Noragric at NMBU, Ian Bryceson, has experience as marine biologist by University of Bergen. He has confirmed that the monitoring methods used today are outdated, and that ROVs would be much appreciated as either a supplementary tool to divers, or even a replacement in some situations.

Together with Ian, the author attended a meeting with Tormatic, a distributor of the YSI sensory systems to get a demonstration of two products that might could be used on the OpenROV.

Lars Dalen is one of *Marinreparatørene*, a group of scuba divers in Norway, who work specifically on monitoring and sensory systems and conservation of coral reefs. According to him, information on where the limit values are, and to uncover potential recovering would be easier to obtain with video recording and sensors combined. (Dalen, 2015)

Ola Callander is a professional scuba diver who has given valuable answers regarding underwater inspection procedures. He has been documenting dispersal of industrial waste from installations and found that the impact on the surroundings was much more extensive than just right under the installation. (Callander, 2015)

8.3 Aquaculture

First of all it was necessary to create a map/picture over all the industrial Aquaculture sites along the coastline of Norway to determine the size and situation of the industry.

Among the most important structural considerations of many marine aquaculture sites are the mooring lines and anchor points of the merdes. To know that the mooring points are sound and intact is invaluable to any fish farmer. When first setting up a merde knowing where your mooring

anchors will be is extremely important - as is avoiding potentially difficult or dynamic areas. A system that can provide a video survey documentation record for the area, allows the decision makers to make the right calls on placement. Knowing that your merdes are where they should be, can prevent regulatory agency action or fines.

8.4 Rescue service

The interview presented below shows the specific questions and answers that were given during a visit at the Fire and Rescue department in Oslo March 10th.

Table 8: Interview with Oslo Fire and Rescue Service

Research questions:	Answers:
<p>Description of work methods.</p> <p>”What are the first actions when the alarm goes off?”</p>	<p><i>When the emergency alarm goes off, we move out immediately. We have two emergency vehicles and the only station that has more than one car available for diving missions.</i></p> <p><i>We call this procedure "lifesaving diving missions" and most often it is about fall from pier or quay, or people who are missing from swimming areas. It may also be yachting accidents and persons that are missing in rivers or freshwater.</i></p> <p><i>Second operation phase is "further search" or SEAO - search for assumed dead. [H. Litland]</i></p>
<p>How many divers do you use on a mission?</p>	<p><i>There are four divers on duty at all time, ready to act 24/7. Those are the first to reach the area, and they will call for more divers if needed. [H. Litland]</i></p>
<p>Problems and pain points in rescue diver service?</p>	<p><i>We need sonar, we must be able to map to show among other things to the police which areas the search has covered. This is a challenge today, as we do not have a good solution to.</i></p> <p><i>Visibility is a challenge, having a picture of the site one diver, which provides more information than one is able to see, would have been of great help. [H. Litland]</i></p>
<p>Are there any restrictions you have to follow?</p>	<p><i>The divers are not allowed to go deeper than 30 meters on search, but obviously we are pushing the limit if we discover a person a little deeper. The reason we do not go deeper, security, and limitation in the type of certificate and training.</i></p>
<p>What are your thoughts on the use of micro-ROV in their work?</p>	<p><i>We have considered having their own ROVs earlier and checked out SeaBotix but the price of the cheapest we found was around 800 000 NOK (>100.000 USD). The cost has been a limiting factor for why this is not in use. [Kenneth Krib]</i></p> <p><i>Having a ROV at the station require some training in use and regularly exercises with the ROV. The more plug-and-play, the easier to implement such solutions when time is a limiting factor here. [H. Litland]</i></p> <p><i>Fire stations where they have no diver service also needs ROV - for precisely this reason, in order to make search before divers are in place. [K. Krib]</i></p>

In addition to the answers given to the interview, the representatives had ideas for improvement and contributed with their thoughts on how the ROV could serve as an effective tool in their work. Among these inputs were some very simple, but valuable; for instance it would be very useful if the tether was made of fluorising colour, so they could follow the ROV to where the missing person were. More powerful lights would also be of great help, and yellow lights are better than white lights under water. To mount the lights on the outside of the tube where the camera is placed would remove glare from the lights on the video. Other more complicated improvements would be a positioning system, a user friendly function for mapping of search areas and tracking exact spots. A water- and shock proof control system that withstands the varying conditions they work under is also wanted.

8.5 Consumer market

DJI (Da-Jiang Innovations) is the manufacturer of the well known drones and a pioneer in the nascent market for commercial unmanned aircraft and has become leading in its industry. The company has supposedly made around \$500m in revenues in 2014 and hence grown rapidly from 2006 when it was founded. (The Economist, 2015)

The drones from DJI and the ROVs from OpenROV have similarities; both are lightweight and easy to use, as well as affordable for non-industrial customers. Supported by the market research findings, it is assumed that small and affordable ROVs may see a market growth that is resembling. "underwater drone".

8.6 Other findings

8.6.1 Interviews and communication

ROV market

Interviews with representatns from the two leading ROV distributors in Scandinavia have given valuable insight to the market situation, due to competition, customers and fields of application.

A market gap has been uncovered, where there are few potential customers of the ROV systems provided to the market today, and it is reason to believe that the high price level is the main factor.

8.6.2 Surveys

Brazil

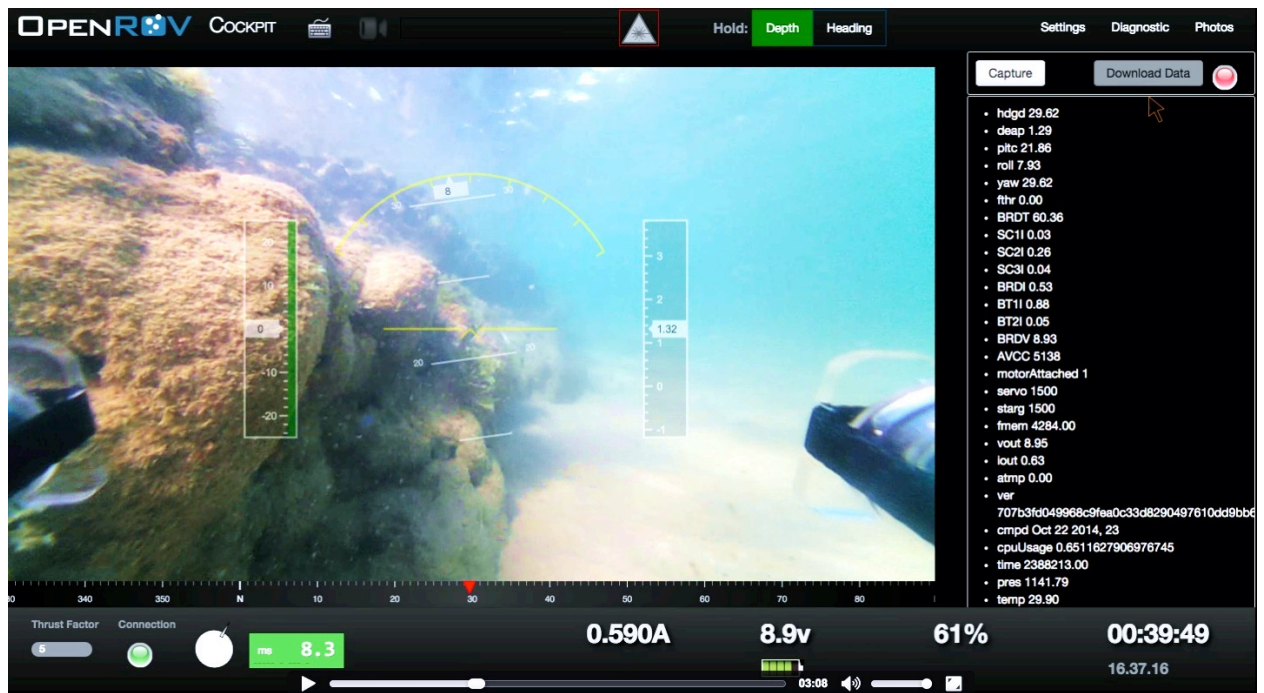


Figure 33: View from the OpenROV cockpit on coral reefs in Barra Grande, Bahia. (Photo: Spiten)

During the stay in Bahia, Brazil two tests have been performed; the first was a test-drive in a swimming pool and the other a survey on coral reefs. The test-drive was done with the YSI MP-556 attached to the rods underneath the body of the ROV, in order to see whether the thrusters were powerful enough to carry the additional weight, and if the ROV would still manage to hold a constant depth. In the swimming pool the ROV was isolated from waves and currents.

The survey on the coral reefs was the next step to investigate how the ROV managed to hold a steady course and to what extent the added sensory system would interfere with its ability to hold depth.

Both of the test gave satisfying results due to the maneuverability of the ROV, and also regarding the sensory system which functioned very well on the OpenROV. It is worth to mention that, at this point, the ROV and the sensory system were only connected mechanically, and there was no communication between the two systems.

Conceptual testings

Many lessons have been learnt during testing of sensors. The main idea has been to see whether the OpenROV 2.7 could serve at a tool for monitoring of water quality and hence be useful in several fields of industry. Furthermore, to uncover unforeseen challenges and opportunities that could come up.

Measuring of pH-level is important to several industries and two of the areas in focus within this project, namely the aquaculture industry and for environmental monitoring on coral reefs. Therefore the focus has been on this sensor, also because only one sensor is needed to prove the concept.

9 MARKET ANALYSIS

This chapter presents the cost calculation of the system that is proposed as a solution, based on the testing results. A market analysis is performed to investigate further opportunities for business establishment and evolve into a business strategy for Spiten Tech.

9.1 Market potential

Based on the multiple industries revealed in previous sections in this thesis, we know that there is a significant market potential for small ROVs.

Sale

Existing distributors of mini-ROVs say that they have seen a growth within the sale of products the last years. Still the sale is low based on the number of potential customers that is presented in previous section.

In 2014 VideoRay sold 10 ROV systems, while SeaBotix sold 6. Both companies could tell that the customers were mostly from the aquaculture industry. This underpins the assumption about the aquaculture as the largest potential customer for small ROV systems. The sale of OpenROVs has been bigger than of the more expensive systems, and it is thus reason to believe that the price is an important, if not *the* most important factor.

Prices

The last few years, prices on technological equipment has decreased tremendously, and thus made tools that previously were exclusive to prosperous industrial companies accessible to private individuals and smaller industries. This trend has increased the pace of technological development and opened up for new application areas for existing tools, remotely operated vehicles (ROVs) being one example.

As mentioned earlier in this thesis, research revealed no competitors to OpenROV when it comes to price because the gap is so big that the products appeal to different application areas. OpenROV is the only ROV, that is affordable for private customers and thus serve the consumer market. Quality, features and reliability of the products taken into account, still leaves a potential group of customers who today does not cover their need, hence they wish for a tool that is smaller than the VideoRay and Seabotix, and more reliable than the OpenROV.

Performance

The diagram in figure 36 shows that an increased level of features and performance on the ROVs indicates significantly higher prices. The price on the most expensive system from VideoRay runs beyond the diagram limit with a price of nearly 270 000 USD, however this system includes sonar, thickness gauge, navigation and positioning system, sampler and automatic search function and thus exceeds the competitors on performance.

Norwegian aquaculture market

Based on the report from The Directorate of Fisheries (see Appendix 1) the potential market for small ROV systems within the aquaculture industry has been visualized in the following diagrams:

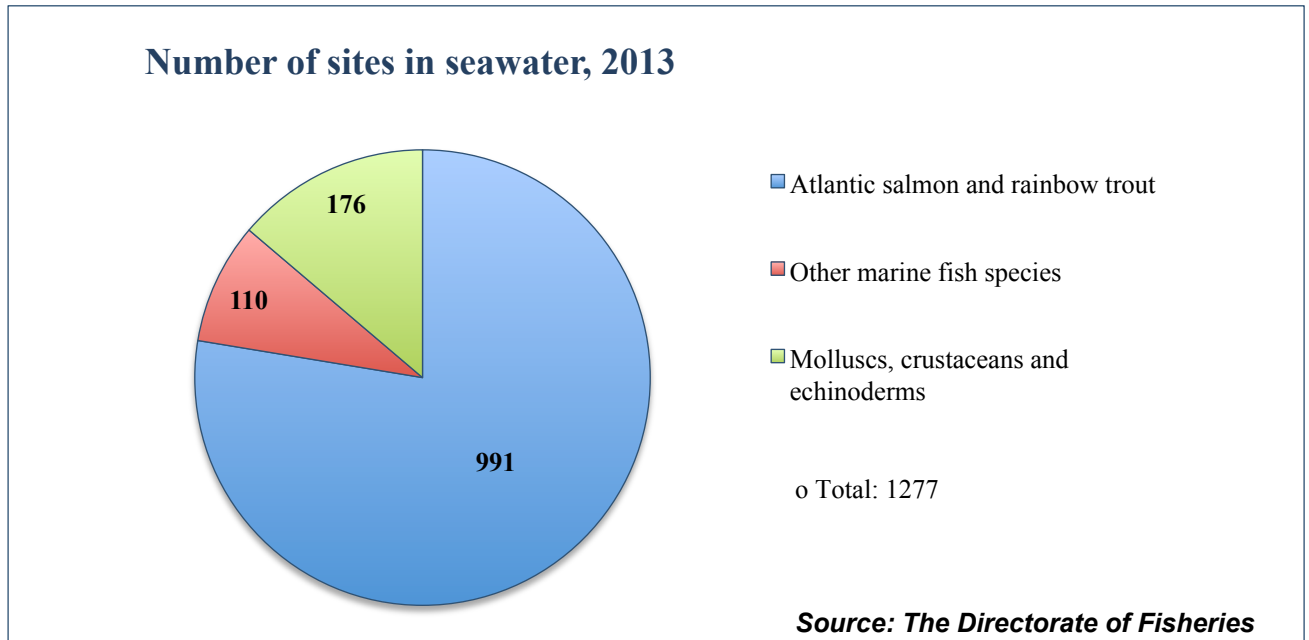


Figure 34: Number of marine aquaculture sites in Norway, 2013. (Illustration: Excel)

The total number of 1277 sites confirm that there is a large potential market within the aquaculture industry. Taking into account findings presented in chapter

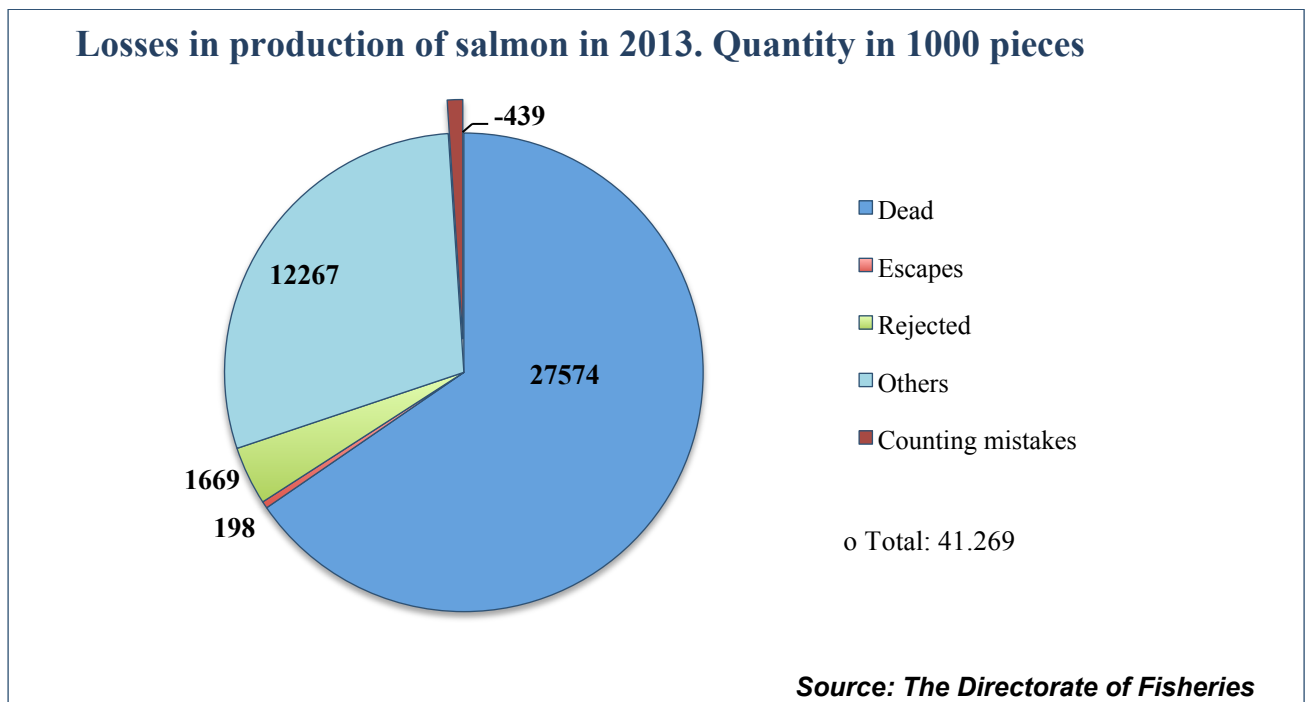


Figure 35: Losses in salmon production in 2013, Norway. (Illustration: Excel)

Definitions:

- Dead fish: number of fish physically removed from the merde because of death caused by illness, wounds etc.
- Rejected: number of fish discarded at slaughterhouse, due to maturity, defects, blemishes etc.
- Escapes: number of fish that have escaped in conjunction with an accident.
- Other losses: Number of fish lost due to predation, theft or other causes.

As mentioned earlier there are large numbers of losses of fish within the aquaculture industry. The diagram above shows the total losses of salmon from Norwegian sites to be over 41 million in 2013.

Comparison of prices and performance level

In the following figure, prices of the two market leading mini-ROV systems are presented. The GNOM ROV is not included.

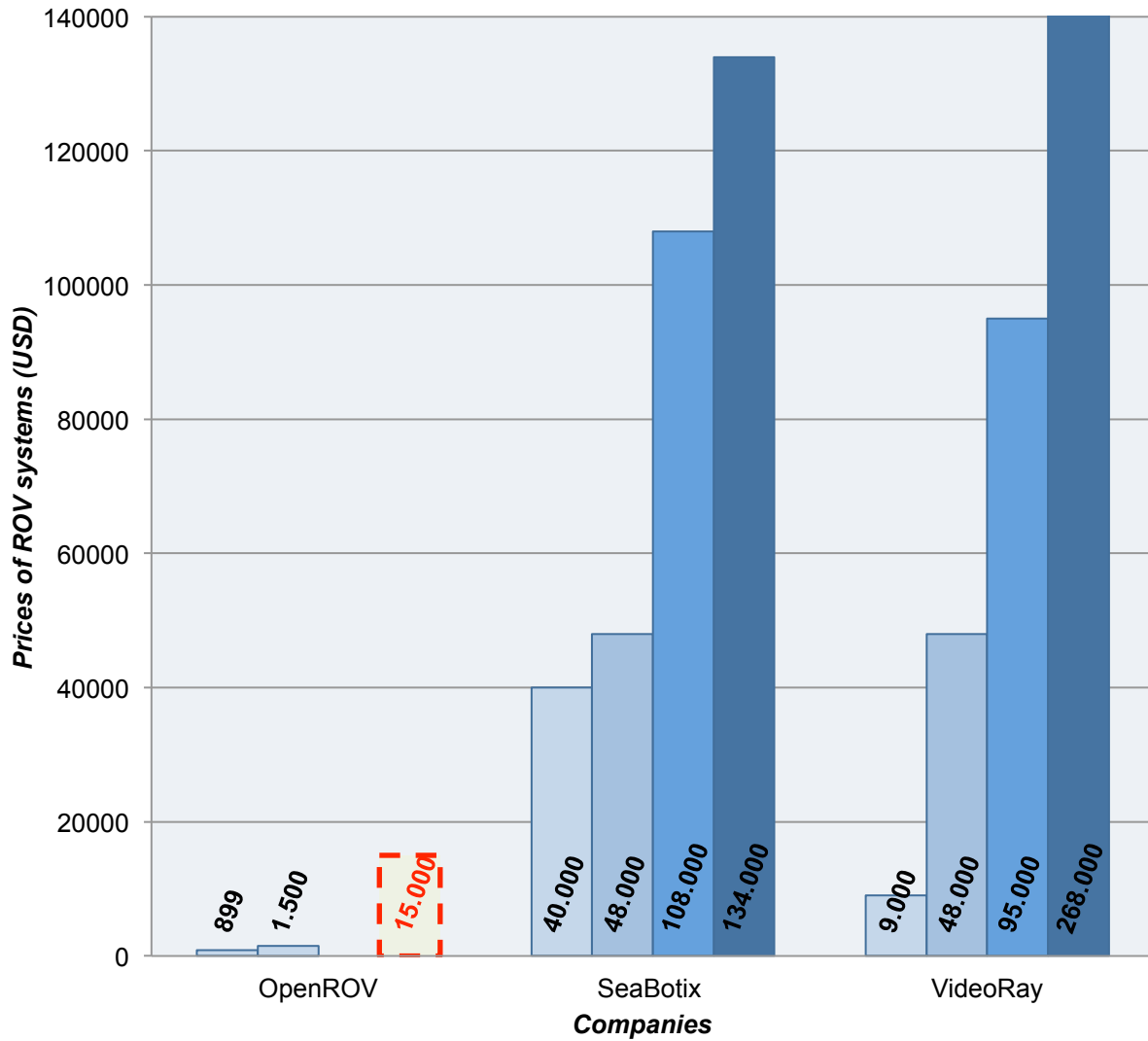


Figure 36: Diagram showing price and performance level of ROV-systems

Performance level	System
Low	OpenROV: v2.7 SeaBotix: LBV 150-4 VideoRay: Scout
Basic	SeaBotix: LBV 200-4, VideoRay: Pro 4 (basic)
Semi	SeaBotix: vLBV 300 VideoRay: Pro 4
Advanced	SeaBotix: vLBV 950 VideoRay: Pro 4 (fully equipped)

As shown in Figure 36, there is a significant market gap between the OpenROV and the most affordable ROV system from SeaBotix that cost about \$40.000. In between these two, VideoRay provide a system for \$9.000 called VideoRay Scout. Scout is an ROV that is similar to the OpenROV due to size, but it lacks features that the OpenROV offers, for a tenth of the price.

Based on findings from the interview with Oslo Fire- and Rescue service (Table 8) and the prices on the competitors in the market, there is reason to believe that a ROV system including the features that the OpenROV v2.7 has today, added sensor technology for measuring pH and oxygen can cost about \$15.000.

9.3 Business strategy

From research done throughout this thesis, the author has taken advantage of the findings and followed a dream about starting her own business. Inspired by colleagues at OpenROV and from the experience gained in San Francisco and from studying entrepreneurship at UC Berkeley the steps towards running a business based on micro-ROVs became smaller.

9.3.1 Spiten Tech

January 10th 2015 Spiten Tech was founded in Ås. The description of the company purpose has been made quite wide so that potentially unforeseen results from the research may be included in the development of a business strategy:

” purchase and sale of technical products, as well as training and consulting services related to these.”

9.3.2 Business model

Business model Spiten Tech

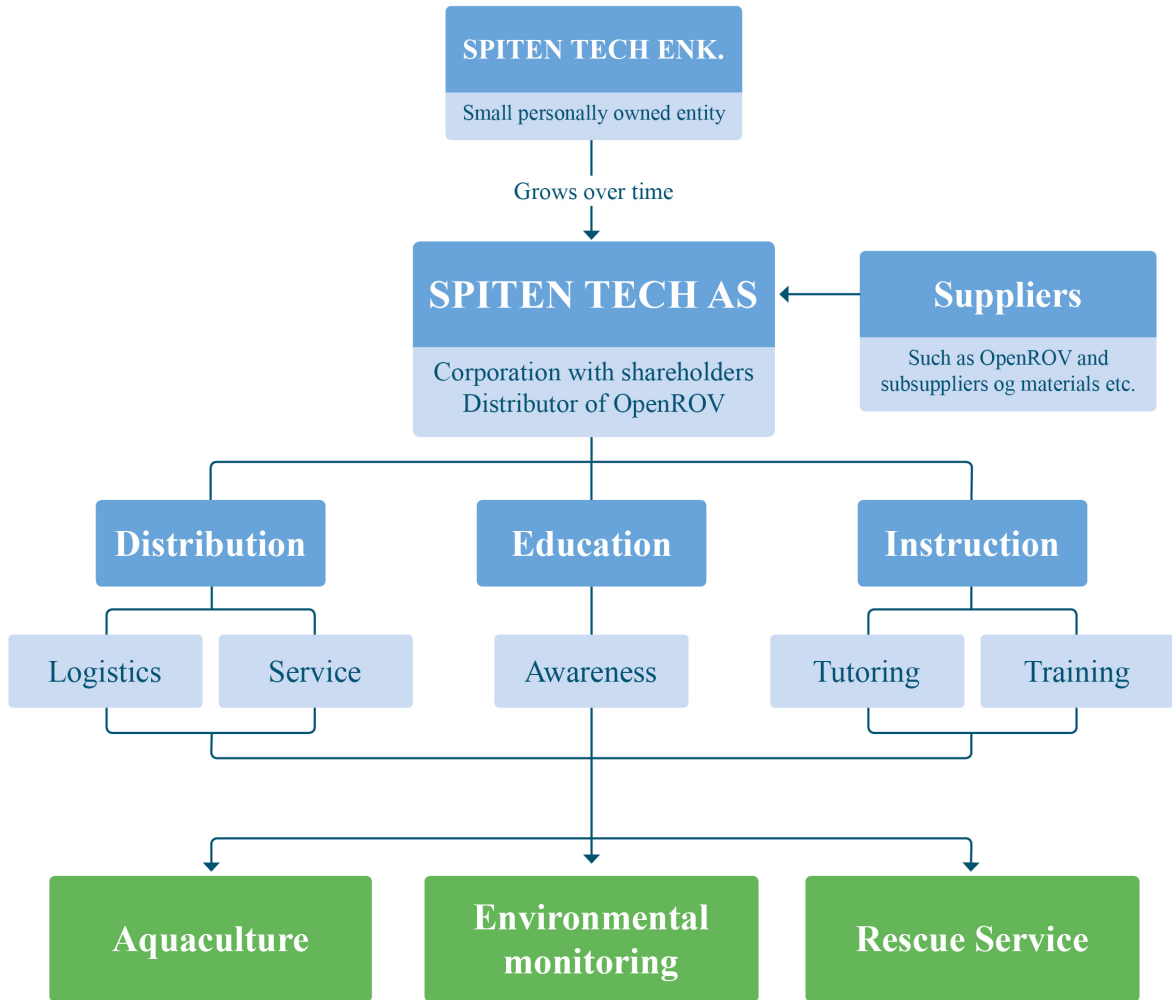


Figure 37: Business model for Spiten Tech. (Illustration: Spiten)

10 PROCESS DISCUSSION

The time schedule for this project has not been very precise. In retrospect it is clear that establishing a company on the side while writing a master thesis has proven to be quite a challenge and far more time consuming than planned. However, the business and thesis have fulfilled each other, and hence most of the activities have been useful and inspiring for both the thesis and the business. I also believe that one would not have received the same amount of insight from doing one or the other. Learning from actually working with the ROVs in practice and in theory is valuable in itself. Coupling that with the business perspective gives the opportunity to attack an emerging and exiting market from multiple angles at the same time.

The thesis ended up becoming more of a guide through the underwater world, yet it recommends staying onshore and use remotely operated vehicles to explore the deep. I hope this thesis can serve as a contribution to further development of underwater monitoring systems, and that the results and tests performed during this study will make future projects thrive. Furthermore, it is my hope that the ideas and concepts resulting from this thesis will help moving ROVs towards a market that has yet to be covered; low cost Micro-ROVs for monitoring purposes.

To investigate a market that barely exists is not a simple task. I was certain that I would get valuable information from the aquaculture industry, and I was ready to travel to the first and best site in order to demonstrate the developed OpenROV v2.7 system, but that turned out to be a lot more difficult than expected. This may be because they are reluctant to give away information to potential competitors or it just might be that the market is so novel that they have very limited historical data to show for.

Through interviews and meetings with potential clients, marine biologists etc. it is clear that the interest for Micro-ROVs is present. People are willing to share their experiences and ideas towards the use of such a useful tool.

Conversations to the two largest distributors of ROVs have clearly been helpful.

It is worth to mention that data and signal transmission through water is difficult, and there have been some challenges with finding the optimal solutions. That being said, perseverance has paid off from testing and the concept we have come up with seems like a plausible solution to implement although the testing was time consuming.

When first starting to work on this project, I had high expectations and ambitions. Several student projects were planned, some of them were major projects abroad and some more local with a shorter timeframe. In common for all the projects were the focus on use of Micro-ROVs for monitoring. Seeing that the testing and concept development have been rather time consuming, it was necessary to limit the overall scope so that one could indulge more into the specific tasks at hand. I believe that this has led to valuable insight and learning to pass on for further projects.

11 CONCLUSION

This project evaluates the market and potential applications for small ROVs. The work that has resulted in this thesis is based on the OpenROV v2.7 and investigation of development and implementation of technical solutions, in order to make the ROV a suitable tool for underwater monitoring. The study gives a clear path to future development projects based on acquired knowledge, literature study, market research and technological concept testings.

It has been demonstrated through that the potential for use of mini-ROVs is wide and that there is a market gap with potential customers whom no product systems appeal to due to cost level.

Consequently, implementing simple and affordable sensory systems on the OpenROV will contribute to expansion in the use of mini-ROVs and fields of application, hence smaller companies and operators may afford the system.

Conceptual solutions have been developed and visualised through models from SolidWorks.

11.1 Results and recommendations

The attempt to use OpenROV v2.7 as a tool for environmental monitoring has been partly successful. Results from two technical testings have led to the following conclusions:

- The first testing with Arduarium Ultimate Controller failed. The Macroduino Code that is meant to be paired with the controller board did not work as planned.
- However, Testing 2 has given satisfying results. Signals from the pH-probe were successfully transmitted from the pH circuit board via an Arduino Uno board to a personal computer. Tests with the probe in water, soda, milk and coffee have been performed and proved that concept to work.

11.2 Further work

This study have been performed in parallel to establishing student projects at the laboratory, *Eik Idéverksted*, at NMBU where students from interdisciplinary study programs follow the course; TEL240 (regulation techniques). This opens for:

- Master projects in collaboration with Associate Professor, Pål Johan From
- Coral reef monitoring project in Barra Grande, Brazil

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13 APPENDIX

Appendix 1:

Data from The Directorate of Fisheries

2. Lokalteter/Sites

Kilde: Fiskeridirektoratet, Kyst- og havbruksavdelingen

Source: The Directorate of Fisheries

Tabell 4. Antall lokaliteter i sjø pr. 31. desember 2013

The number of sites in seawater per 31 December 2013

	Laks og regnbueørret <i>Atlantic salmon and rainbow trout</i>	Andre marine fiskearter <i>Other marine fish species</i>	Bløtdyr, krepsdyr og pigghuder <i>Molluscs, crustaceans and echinoderms</i>
Fylke <i>County</i>	Antall <i>Number</i>	Antall <i>Number</i>	Antall <i>Number</i>
Finnmark	67	9	0
Troms	111	8	3
Nordland	205	31	33
Nord-Trøndelag	63	5	23
Sør-Trøndelag	93	3	21
Møre og Romsdal	88	13	6
Sogn og Fjordane	86	12	11
Hordaland	191	10	36
Rogaland	73	16	14
Vest-Agder	12	1	7
Aust-Agder	2	0	21
Øvrige fylker	0	2	1
Totalt/ <i>Total</i>	991	110	176

Appendix 2:

Data from Oslo Fire- and Rescue Department

Drukning etter kategori	
Drukning Kai/Havn	61
Drukning Annen Kommune	65
Drukning Marka	16
Drukning Elv	24
Drukning Båt	10
Drukning bil i sjøen	1

Drukning etter år	
2012	47
2013	56
2014	74



Appendix 3:

Arduino Code used for pH measurements

```
#include <Wire.h>
#define address 99

char computerdata[20];
byte received_from_computer=0;
byte serial_event=0;
byte code=0;
char ph_data[20];
byte in_char=0;
byte i=0;
int time=1400;
float ph_float;

void setup() {
  // put your setup code here, to run once:

  Serial.begin(9600);
  Wire.begin();
}

void serialEvent() {
  received_from_computer=Serial.readBytesUntil(13,computerdata,20);
  computerdata[received_from_computer]=0;
  serial_event=1;
}

void loop() {
  // put your main code here, to run repeatedly:
  if(serial_event){
    if(computerdata[0]=='c'||computerdata[0]=='r')time=1400;
    else time=300;

    Wire.beginTransmission(address);
    Wire.write(computerdata);
    Wire.endTransmission();

    delay(time);
    Wire.requestFrom(address,20,1);
    code=Wire.read();

    switch (code){
      case 1:
        Serial.println("Success");
```

```
break;

case 2:
  Serial.println("Failed");
  break;

case 254:
  Serial.println("Pending");
  break;

case 255:
  Serial.println("No Data");
  break;
}

while(Wire.available()){
  in_char = Wire.read();
  ph_data[i]= in_char;
  i+=1;
  if(in_char==0){
    Wire.endTransmission();
    break;
  }
}

Serial.println(ph_data);
serial_event=0;
}
}
}
```




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