2018-2019

FINAL REPORT
SEASU

PdP | PRODUCT DEVELOPMENT PROJECT

Sponsored by SAAB


SEASU

TABLE OF CONTENTS

INTRODUCTION

The brief for this Product development Project (PdP) course project was to innovate, design and prototype a device that uses underwater technologies already existing in the sponsor company Saab's products. A specific use case was to be created outside the usual Saab product application areas and the potential market for the product had to be researched. The sponsor company Saab is leader in the field of maritime advanced technology.

The prototype was to be designed so that it operates underwater, on the seabed or in the water column. It should also withstand a chemically aggressive condition occurring in the sea environment and have a user-friendly controlling system. Aim of this project included also making the end product cheaper than Saab's regular products, affordable even for an average customer; therefore, emphasis was put also for the design aspect, to make the output smart and elegant, good looking and inspiring.

In addition to creating a new product, objective of the project was to learn as much as possible, after all, it was executed in a university course. Learnings were gained in the fields of project management, project working, research, finance, coding, prototyping and communication. The project was executed between September 2018 and May 2019 and the maximum budget available was 10.000 EUR.

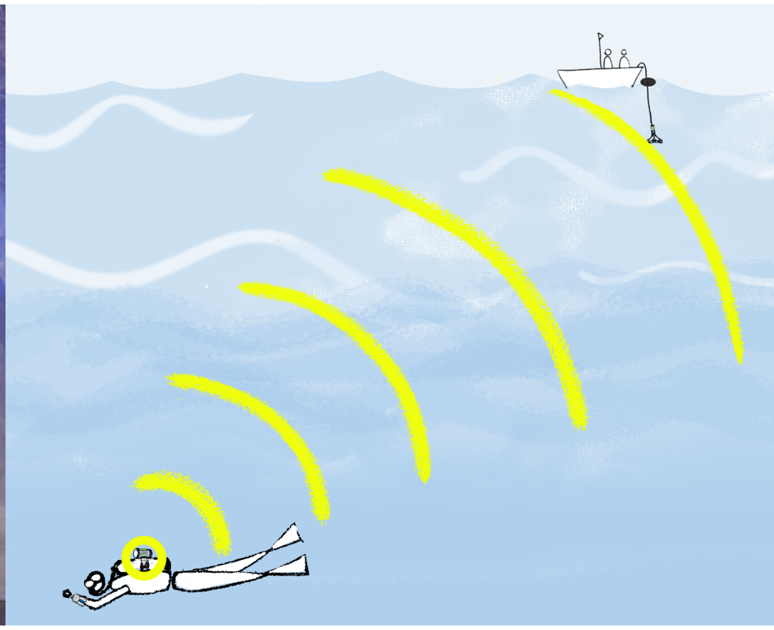
In this final report for team Seasu, first the components of the created product are introduced. Next, the project stakeholders and used methods are introduced. After that, the project progress is explained in order from discovery to development and testing. In the end, future development possibilities are briefly discussed.

PRODUCT DESCRIPTION

The diver localization, navigation and messaging enabling Seasu kit consists of the following components.

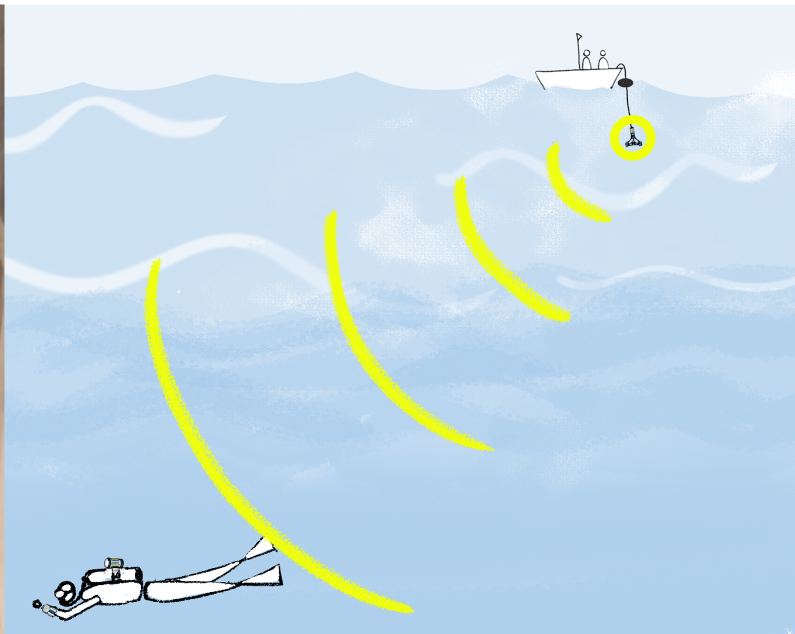
Diver sound emitting unit

This unit is attached to the diver and emits a sound wave that travels through the water. Sound emitting unit contains a pressure sensor, microcontroller, battery pack and a piezoceramic speaker. From the measurement of the pressure sensor, the depth can be calculated. The depth information is encoded to the pulsating sound waves.



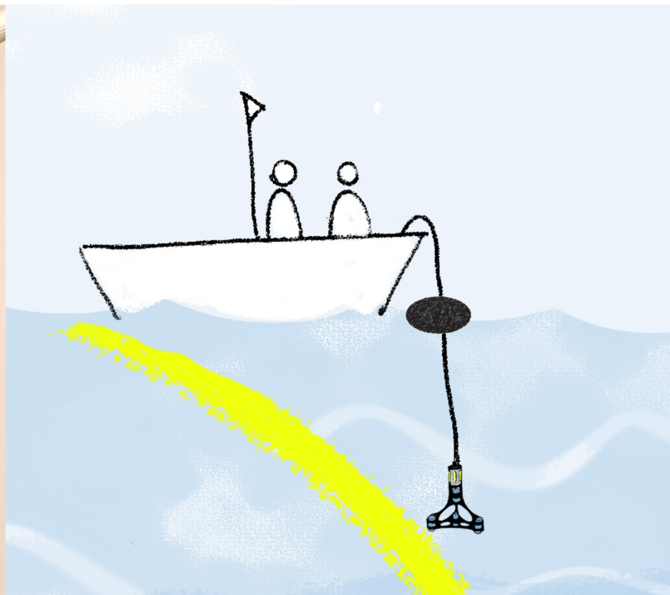
Hydrophone unit

Hydrophone unit is hanging in the water column from the surface unit with a steel wire. Hydrophone unit consists of four hydrophones and an orientation sensor. As the sound waves reach the four hydrophones, the direction of the sound source can be calculated. Orientation sensor is used to know in which position the hydrophone unit is so that provided direction is correct. Data is transferred through cable to surface unit. Hydrophone unit is illustrated on the next page.



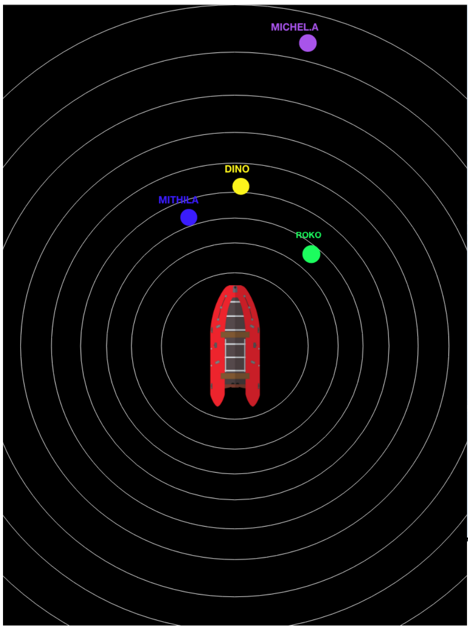
Surface unit

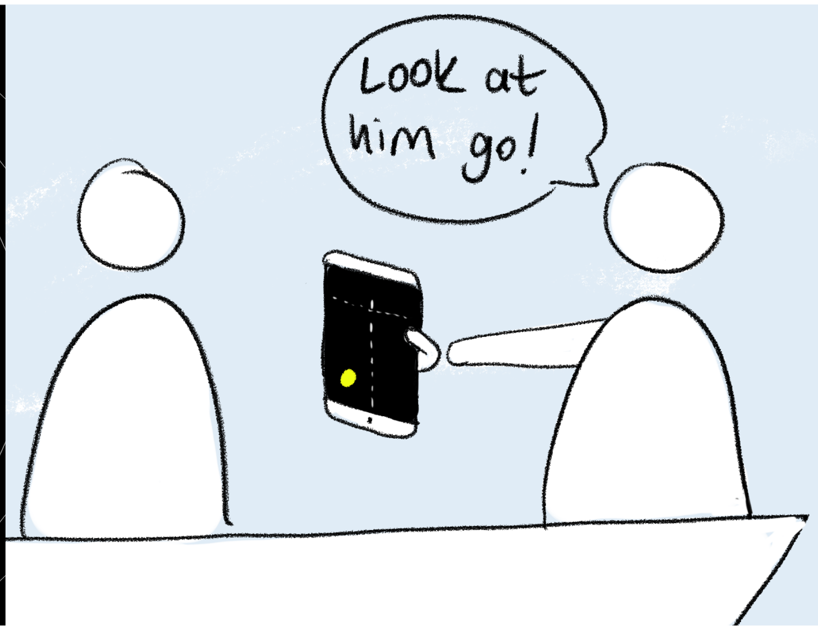
Surface unit is floating on the surface and attached to a boat with a telescopic pole. The pole is able to rotate up and down and it's there to prevent the unit hitting the boat. Surface unit contains a microcontroller and a power bank. The data from the hydrophone unit is conveyed to the microcontroller in the surface unit and the processing is done. The depth data encoded to the sound waves is decoded and with the direction information, the location in 3D coordinates can be provided. 3D location information is sent over Bluetooth communication.



App on Android

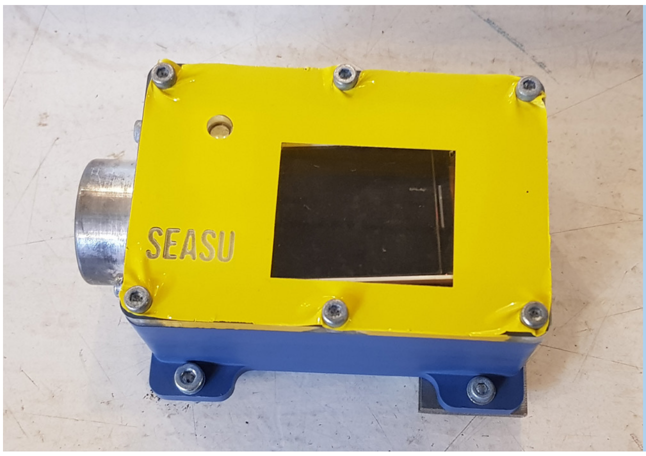
A Seasu app is installed to an Android device that is used by the surface team in the boat. The device is connected to the surface unit via Bluetooth and the app shows the location and depth of a diver who equipped with the sound emitting unit. The app also enables the surface team to send messages for the diver receiving unit using a hydrophone in the hydrophone array as the speaker for sound waves.

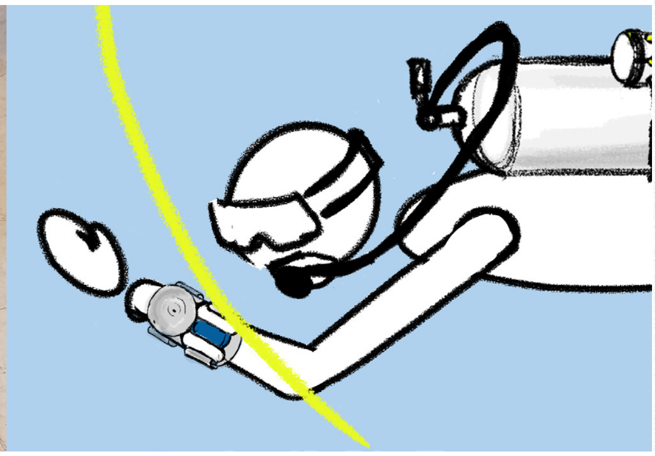




Diver receiving unit

Diver receiving unit is installed to the wrist of a diver. It consists of a display, battery, hydrophone and a microcontroller. The messages sent from the App are picked by the hydrophone and displayed on the screen. The location information can be also sent to the diver receiving unit, enabling it to calculate and illustrate the direction back to the boat or to some other wanted navigation target.





STAKEHOLDERS

Team

Team Seasu was one of the teams taking part in the PdP course in the Design Factory in Aalto University. Team consists of 8 members with different backgrounds such as Mechanical Engineering, Industrial Engineering and Management, Industrial Design, Mechatronic Engineering and Electrical Engineering. Members are from Turkey, Italy, Finland and Brazil.

The Turkish, Italian and Finnish members are located in Design Factory in Espoo, Finland and the Brazilian members are located in Design Factory in Sao Paulo, Brazil. Having an international team enabled for example interview divers in both warm and cold environments. It was also possible to compare prices in the two countries and source components where they were cheaper. Naturally, the division of the team in two countries led to occasional communication problems, but the members located in two different countries communicated weekly through various online platforms to work on the project and follow the schedule.

Saab

Saab, the sponsor for the Seasu project, serve the global market with world-leading products, services and solutions from military defence to civil security. One of the fields Saab works on is the Naval Industry. Especially in the littoral waters the shallow depths, complex hydro-acoustic environment and sometimes dense civil traffic result in an ever-changing situation. Saab develops sophisticated underwater weapon systems, sensor systems and sub-surface equipment for these environments to help their customers enhance their defence capabilities. Saab has multiple offices around the world and underwater research and development is located in Linköping, Sweden and in UK.

Collaborating and becoming a part of the PdP, Saab aimed to develop new use cases for their existing technologies. Contact person from Saab for the project was Petteri Alinikula and he is located in Saab Helsinki office. As a project sponsor, Saab gave team Seasu rather free hands to make decisions along the project.

Aalto University

Aalto Design Factory
Design Factory in Aalto University is the home for the Product Development Project (PdP) and it brings the sponsors, Aalto students and global teams together. PdP staff consists of professor Kalevi Ekman and two assistants Aimane Blej and Andre Santos.

During the project, course staff helped in case of questions or problems. DF machine shop people Vesa Saarijärvi and Kari Kääriäinen were helping the team with design and manufacturing. Lots of help with the electronics components were offered by David Leal and Shreyasi Kar from Design Factory.

Other Aalto University Facilities
Aalto University has also other facilities available for research, development and manufacturing. During the project team Seasu utilized the spaces in Väre for water-jet cutting and designing. The team had meetings with research staff of Aalto University in Aalto Acoustics lab and in the building of Industrial engineering.

University of Sao Paulo

Sao Paulo Design Factory
Global team had access to the facilities of the Design factory of the university and the International Projects Development Room.

Other Facilities of University of Sao Paulo
The university also provide access to other mechanical and electrical laboratories.
In addition to that, the students can use the facilities of the CITI (Interdisciplinary center of inter- active technologies), having access to an industrial manufacturing line of printed circuit boards.

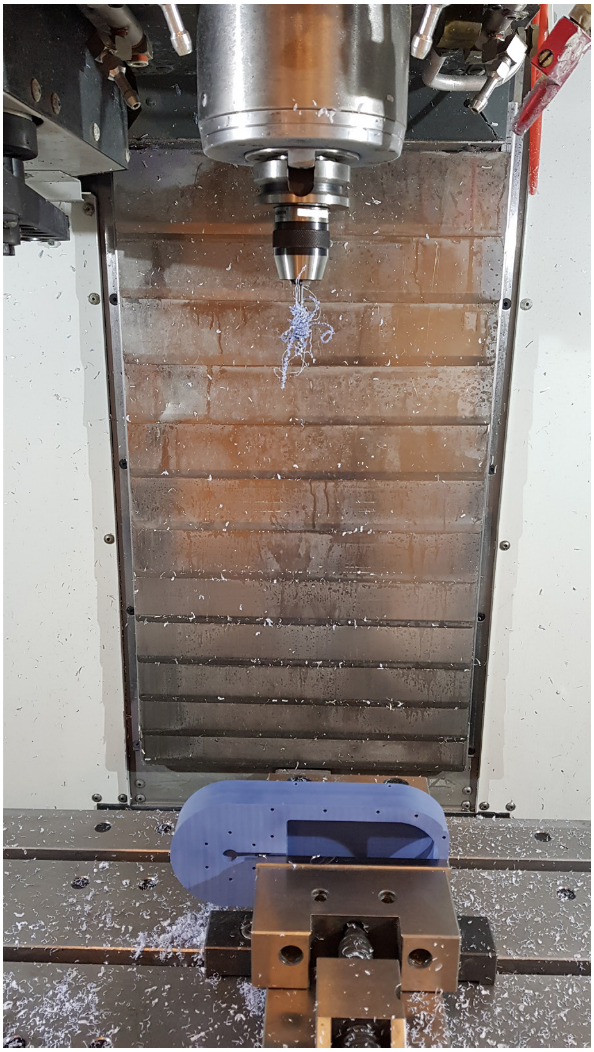


Figure 1. Diver sound emitting unit in CNC machine at Aalto Design Factory

METHODS

Product development process

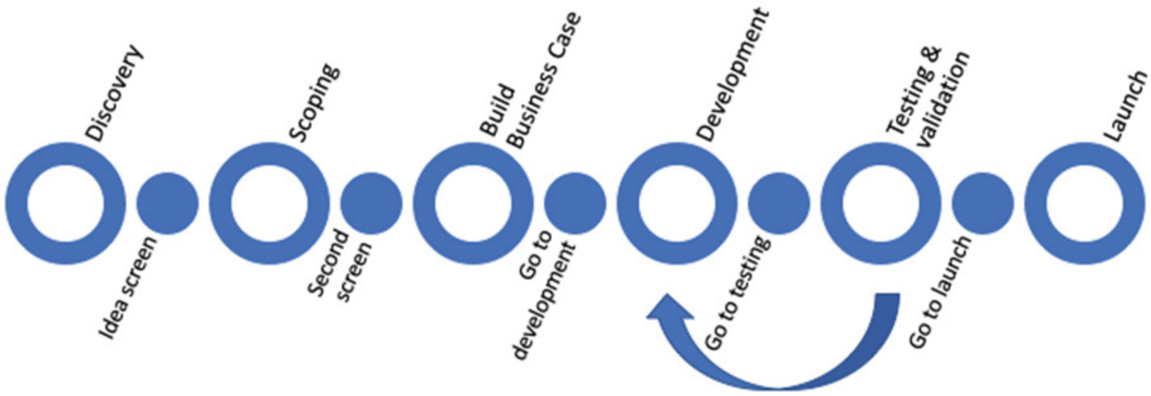


Figure 2. Stage-Gate process by Cooper

The project was framed by the Stage-Gate -process by R.G. Cooper, although in this project the process was not that strict due to iterative and parallel development process. This final report is constructed almost in the same order as the Stage-Gate figure shows. The stage is always explained in the beginning of the chapter and the most important findings and activities done in that phase are presented.

Communication

Skype meetings weekly
Weekly Skype meetings were held at a favorable time for both countries.
These meetings took place in order to update the whole team about the events of the group in an official way, the progress of the meeting being recorded in the meeting notes stored in Google Drive. Depending on the schedules of the team members, sometimes the whole team in Finland participated the Skype meetings and sometimes only the Project manager from Finland.

Telegram
For more direct and objective communications that needed immediate answers, the chosen communication medium was Telegram, since it contained specific chatbots to organize the work developed, as well as quick polls on small pivots of the project. Pictures and videos about the project progress were sent to the group chat and smaller groups were created among the group concentrating to a specific topic, such as electronics.

Finnish and Brazilian Meetings
In addition to the joint meetings by Skype, physical meetings were organized. In weeks, where a Skype meeting with the whole team was not possible, a separate meeting among the groups in Finland and Brazil was arranged. Meeting notes were created of these meetings as well, and stored in Google Drive.

Seasu-Saab Relation
In order to communicate the progress of the project, emails were sent weekly to the Saab representative. Also, some face-to-face meetings were held in Aalto Design Factory and some Skype meetings along the project. Contact person was met in the PdP Checkpoint meetings, and in some additional project team meetings. In major decision-making points, the opinion of contact person was asked, and while deciding for the final project topic, a questionnaire was sent to a larger group of Saab personnel.

Google Drive
All the documents and meeting notes used by the team were stored in shared Drive folder. This way it was ensured that all have access to the same and latest documents. It also acted as a back-up if something would have happened to personal devices.

Time logging

It was decided that the spent time should be tracked to be able to evaluate later whether the time was spent smartly. A small research was conducted to find suitable platforms, but none of them provided an easy way to log the hours categorically. One of the reasons why existing solutions weren't appropriate was that team members wouldn't like to have an external app or use a specific website just for that purpose.

The first solution was to add hours to a shared Google Sheets -document, but soon it was found out to be too time consuming and annoying. Thus, there was a demand for a more simpler time logging solution. The positive aspect of Google Sheets was that it didn't require any new services. It was already included in our Google Drive -folder.

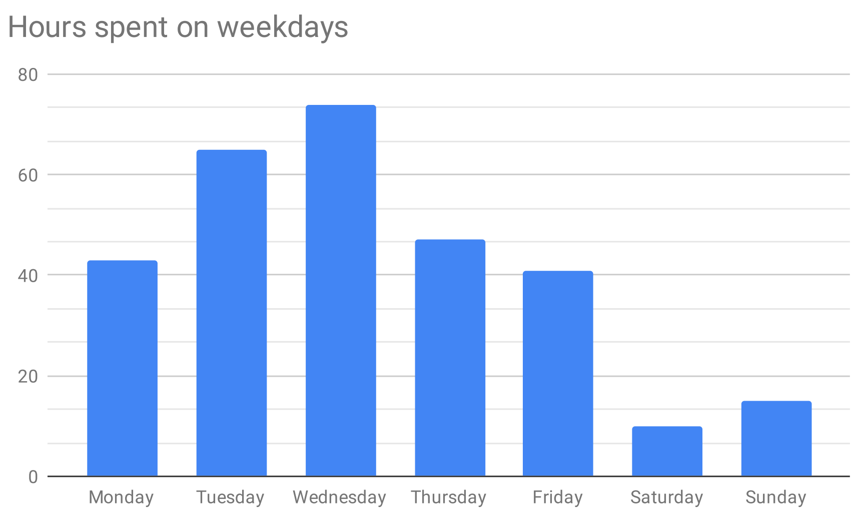


Figure 3. Weekday graph from time logger

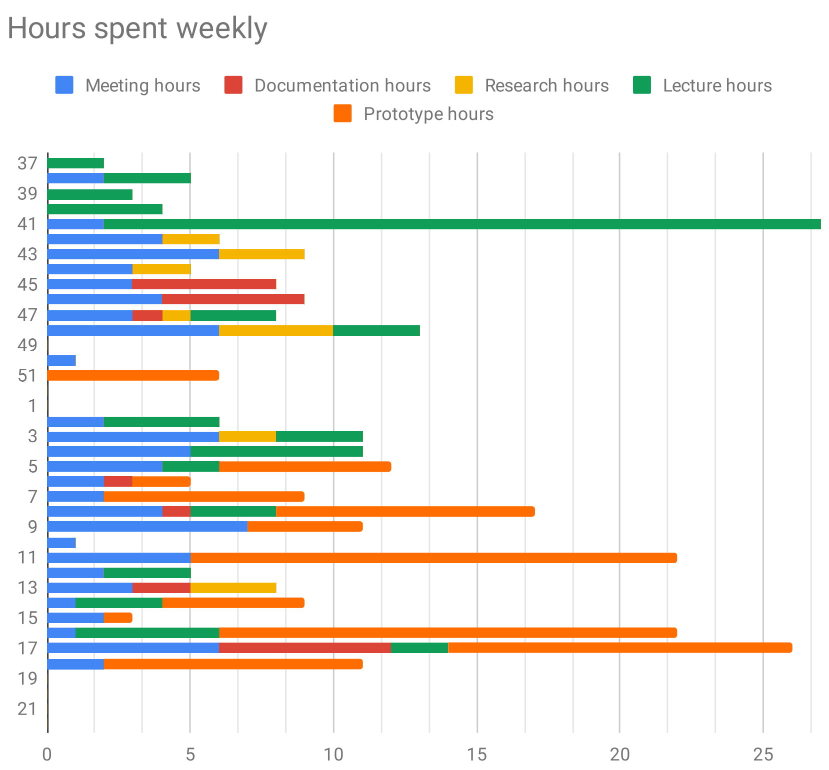


Figure 4. Weekly graph from time logger

It was also good place to visualize the hours, since it allowed making graphs etc. Therefore, it was decided that the hours would be logged into Google Sheets, but not directly. It was found, that Google Forms would be a suitable alternative, because it didn't always have to load the whole document and one could put the hours in much faster and conveniently. That, however, required a personalized script.

Google Drive enables the use of personal scripts, which meant that the data could automatically be sent from Forms to Sheets. After some Javascript programming a suitable script was written, that was able to insert the hours to each person's own sheet, to a correct date and category.

Logging of the time makes it also possible to visualize the hours easily. Such examples are given in Figures 3, 4 and 6. Now, while not part of our product, this solution could be used by project manager easily to see if too much time is spent on something less urgent. For example, if most of the time is spent on meetings, it can be easily seen from the graphs. Or for example if people are working on weekends the current deadlines might be too demanding to meet. Tool itself can be seen in Figure 5.

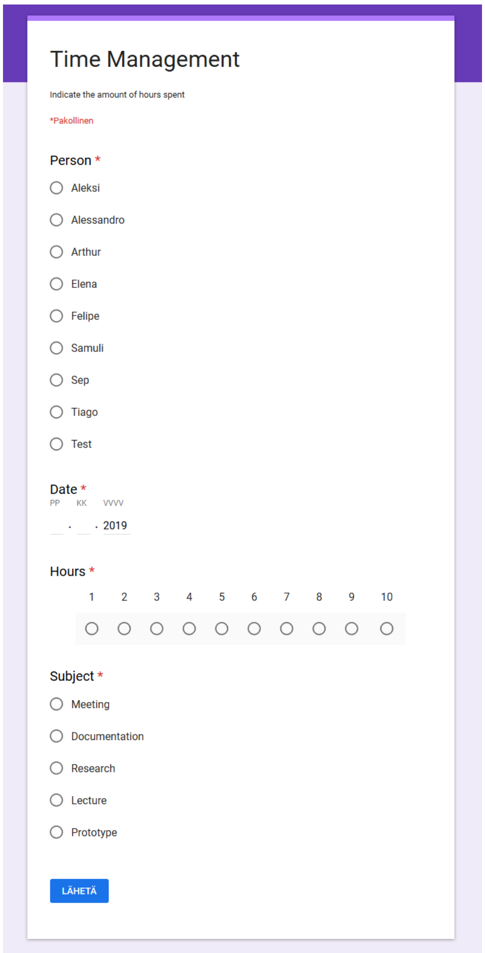


Figure 5. Time management tool

At the time of writing the document the code for the script can be found from: *https://github.com/Muikkunen/Time-management*

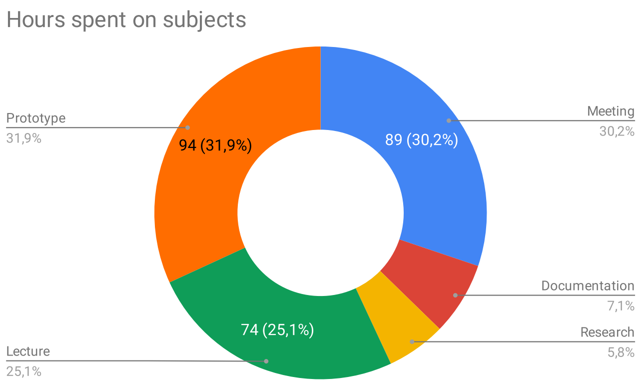
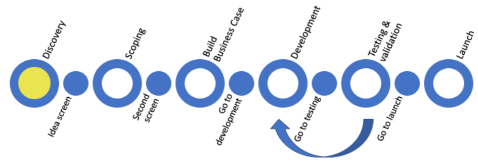


Figure 6. Time spent by subjects

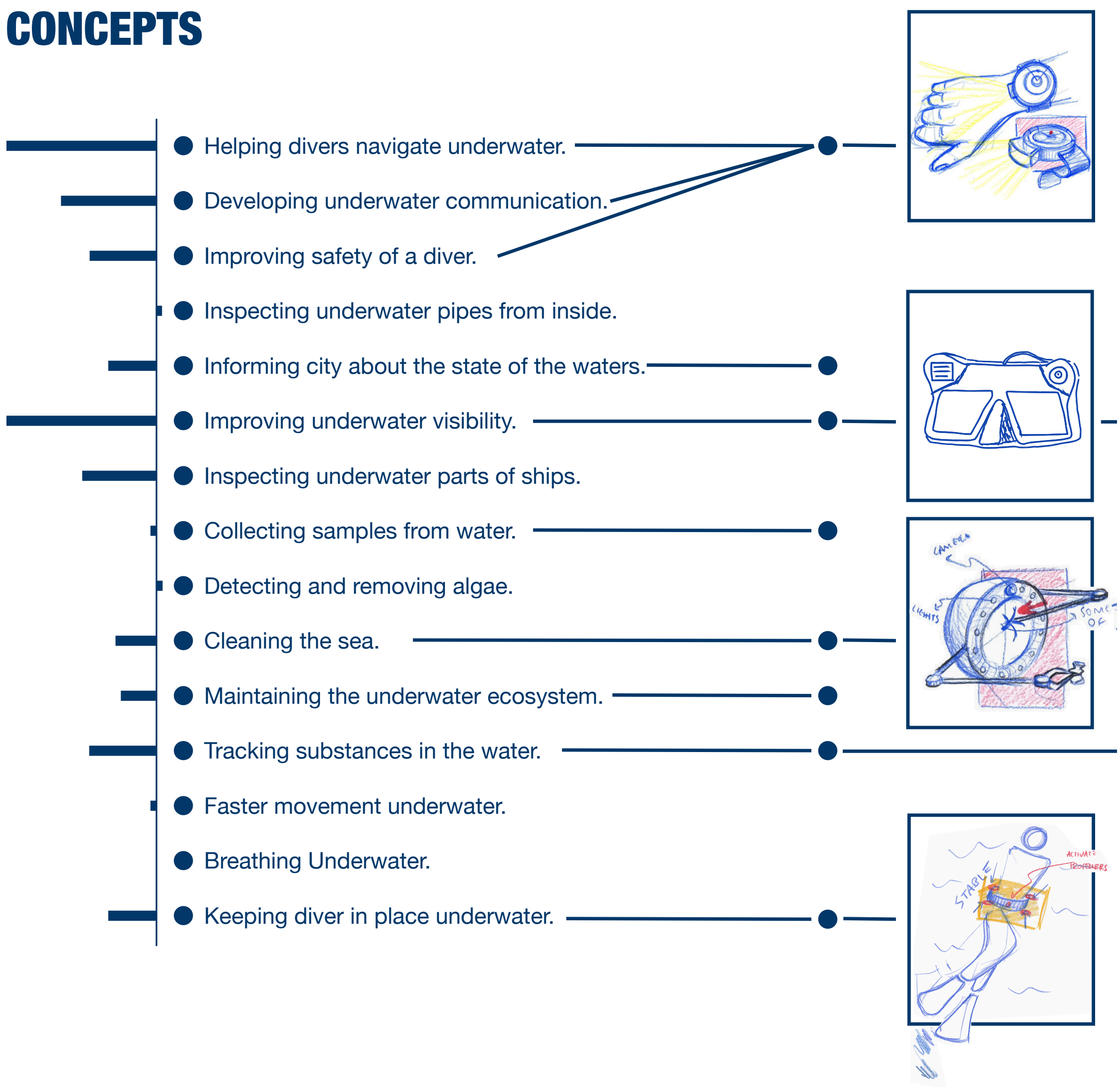
DISCOVERY



In the Discovery phase the problems, that could be solved in project, are discovered. This is done through interviews, online research and brainstorming. In the idea screen, most promising scenarios are passed through.

Idea screen

As the initial project brief was very open, the discovery part of the process was very crucial. This was also emphasized by the sponsor company, as they wanted to generate as much new ideas during the process as possible. The team gave the problem finding a lot of time to find a topic that has commercial potential and is also inspiring for the team members.

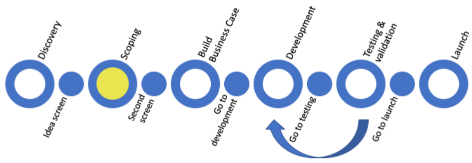


More than 20 interviews were done by calling, face-to-face meetings and e-mailing in this phase. Interviewees were working for example in the army, cargo port, shipping company, academia, diving organization and in technical diving company. The team interviewed also an underwater photographer and a lifeguard trainer.

Figure 7. Meeting at Saab Finland office with Petteri Alinikula on the left

Figure 8. Learning underwater design from last year's PdP Project manager Manuel Rosales

SCOPING



In Scoping, knowledge of the selected topics is deepend and solutions for the problems are ideated. In second screen, only one problem scenario is passed through and the project scope is crystallized. This is done by objectively scoring the different problem scenarios. From the second screen, 3 best solution concepts are taken forward. Rough prototyping is started in this phase to demonstrate different solutions.

Second screen

The team managed to gather a wide range of ideas from different industries. As seen in page 14, it was also possible to combine some of the ideas into on concept. An online research was conducted for all of the ideated concepts and knowledge of the topics was shared among the team.

In addition to online research, visits were made to a diving club and Divers University. Also, a workshop was held for experienced divers to see their opinions and attitudes more specifically towards the diver localization concept.

After thorough analysis of the scenarios, an anonymous poll was organized among the team. Everyone in the team could point the concepts and after the vote diver localization and improving visibility underwater concepts had the most points as seen in Figure 9. Substance detection by ROV was raised as the third concept after talking with sponsor.

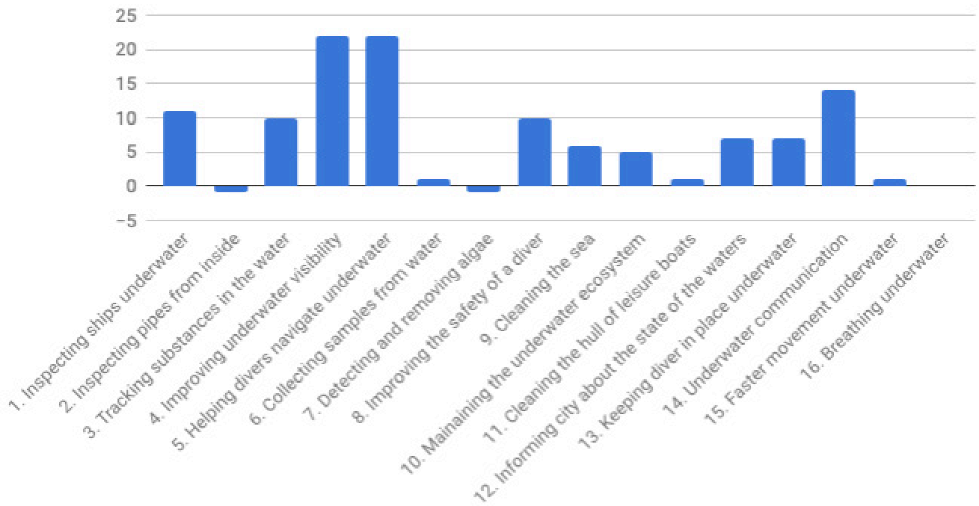
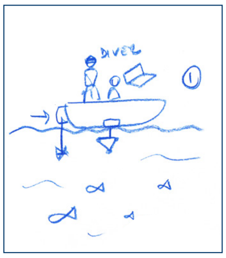
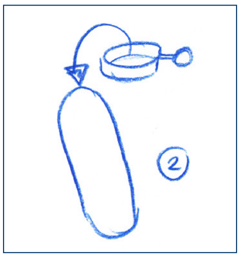


Figure 9. Vote results

CONCEPT 1 - 3D DIVER LOCALISATION

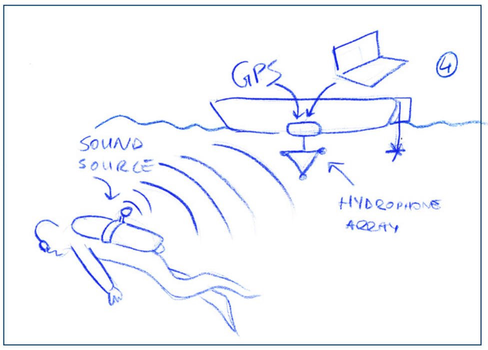


The diver goes to the diving point with other divers, with a buddy or alone. A hydrophone array is lowered into the water.



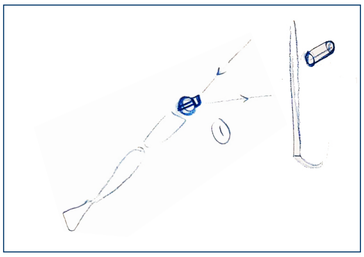
A ring is placed around the diver's air tank. The ring has a sound source which emits signal in a certain frequency.

The diver goes into the water and starts going deeper. The depth data of the diver is conveyed via sound signal pulses.

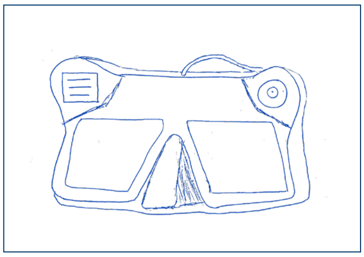


The hydrophone array detects the direction of the diver. By having direction and depth data, the exact location of the diver can be calculated.

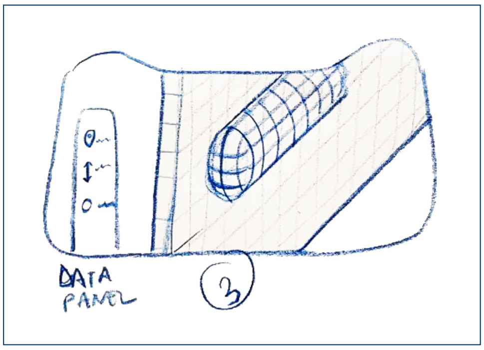
CONCEPT 2 - VISIBILITY ENHANCING GOGGLES



The diver approaches the maintenance pointwearing the goggles.

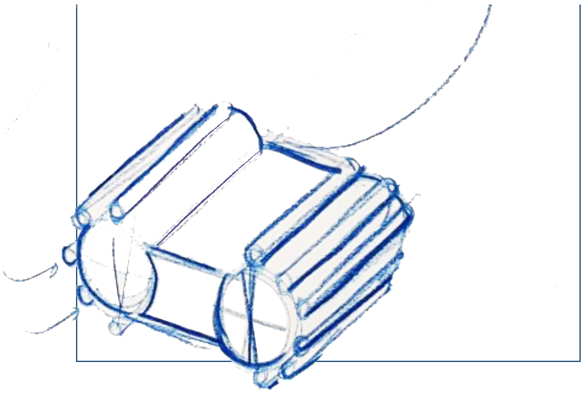


The laser beams are emitted onto the object and the receiver collects the returning beams. This creates a 3D scan of the object.



The image of the scanned objects is projected to the diver's goggles along with a data panel of certain variables.

CONCEPT 3 - SUBSTANCE DETECTION



An rov housing a number of capsules collects samples of water to detect the substances present.

Diving club research visit

A visit to the diving club Kupla was organised after the halfway show in order to get insights and feedback from a professional diver about the first half of the process. The concept was presented to Ulla Kyllönen, the Chair of Board in Kupla. The visit was based around benchmarking and current technologies related to underwater navigation and communication.

Figure 10. Examination of dive computer features

There are several points made about navigation used today such as the malfunction of the current compasses in ferrous waters, the inconvenience of placing the guiding ropes, the inaccuracy of sonar technology and high price ranges. Following these issues with existing technologies, the technology and use cases offered by Seasu were discussed in order to pinpoint the potential issues that may arise in the concept.

The dives done in 30 meters or deeper contain more risk and therefore it is unlikely for divers to trust solely on technology in these depths. The current solution for safety during dives organised in 30 meters or deeper, is the guiding rope. According to Kyllönen's statement, a new technology that would eliminate the rope must be very reliable and proved for the users to add it to their kit.

“Protocol is that there is almost always somebody on the boat, so the boat doesn't run away. The dive leader is following the divers' timetable. If somebody is taking longer than they should, it might be that they are stuck or they are fixing something. If the dive leader knows that the late people are in the 6 meter range, he knows they probably will be fine. If the dive leader knows which depth people are, that would be really, really nice to know. I would be really prepared to pay for that information”, Kyllönen stated.

The main outcome of the visit to Kupla revolves around the idea of improving diver safety and operation efficiency through establishing full access of divers' locations to the dive operator on the surface team. The dive routine would become much more manageable and the diver safety would improve if the location of the divers is known ın the surface. The most important role of the Seasu Kit is tracking location based on the timetable which is determined before each dive.

Research visit to Santos

A visit to the Divers University at the city of Santos in Brazil was done on January 22 of 2019. In there, the global team was able to truly experience the routine of some professional divers, and also feel the ambient of preparation for those who intend to work on the field.

Company visit

Santos is a large coast-city near São Paulo that developed its economy majorly around the Port-of-Santos, one of the biggest ports in Brazil. To supply the port's needs, some very particular companies naturally emerged, including companies which offer diving services. The applicability of our product for commercial purposes was to be evaluated with a visit to one of the companies.

The Diver Sub Serviços Subaquáticos LTDA , works on any kind of service that demands diving at depths not larger than 150 meters. On a long conversation with the CEO of the company, some use cases of application to the product came naturally. One of the problems faced by the company was the repair of submerged structures by rough means, involving masonry, or even by more precise means, such as welds that demanded high precision from the operator. Most of the time, however, when diving for the repair of a structure, the diver would have to search for an extensive area due to the horizontal displacement during the descent from the vessel. In this condition, a device that would accurately tell the diver's location would greatly expedite the process, saving up to days of work that is sometimes lost due to the uncertainty of the diver's descent.

Figure 11. Hyperbaric chamber used for depressurization

However, technical divers are required by law to use cords attached to them in Brazil. This means that even when establishing a good communication between the diver and surface team, there needs to be some kind of physical restriction.

University visit

After the promising conversation with the underwater services company, the global team visited Divers University, which is Part of the Metropolitan University of Santos. There are taught practical courses for those seeking to work in the dive business. The courses are quite extensive and have a very high requirement to achieve the excellence demanded by the Laws of the Brazilian Navy.

Figure 12. Global team visiting Diver University

On this occasion, it was possible to hear from the professionals who teach on the site some stories of adverse dives in murky waters with very impaired visibility that would certainly favor the use of the product developed by the team. The visit allowed the global team to establish contact with the end user's daily routine and brought clear demands on the usability of the project. Some important physical restrictions were learned as well, that would have been disregarded had the visit not occurred, such as: voltage limits for marine equipment, weight of equipment, size of equipment and restriction of equipment to be taken with the diver.

Underwater communication

First hydrophone array test
The team learned, that in Aalto University there are projects in the Acoustics laboratory, which are related in hydro acoustics. PhD student Leo McCormack was contacted, and a meeting was held. Inspired of the learnings, first transmission test was undergone on the 20th December 2018, in a private swimming pool. The aim of the experiment was to examine the operations between the speaker and the hydrophones array. The team loaned the following equipment from Aalto University Acoustics and Signal Processing department to conduct the test:

- Hydrophone array (4xAquarian audio H2a hydrophones)
- Underwater speaker (Oceanears DRS-8)
- Impedance matching transformer for underwater speaker
- Signal amplifier

For signal sending and hydrophone recording, the following private equipment was used:

- MacBook Air
- USB interface (Focusrite Scarlett 18i20)

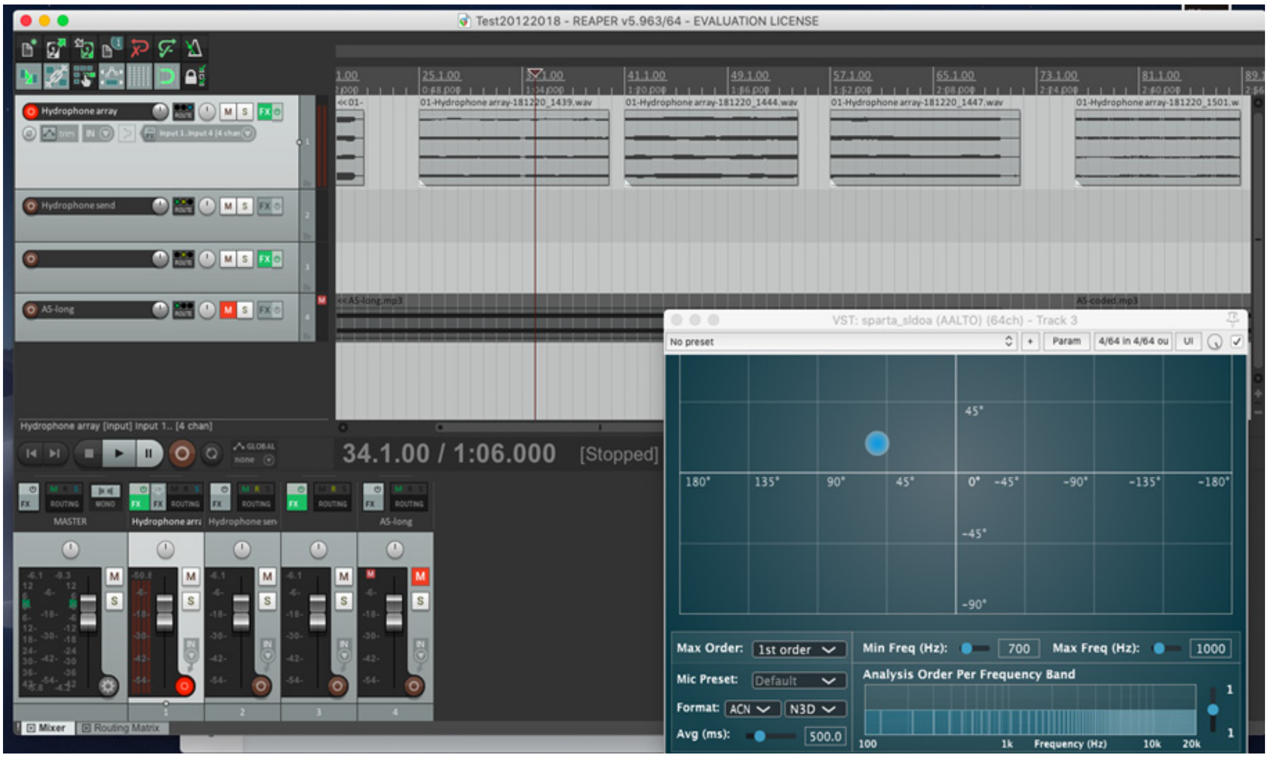


Figure 13. Screen capture from the experiment. 4 hydrophone channels at the top and blue dot representing the direction of the sound in the bottom right window.

The laptop's programmes used to lead the experiment and analyse the results are the following:

- Logic Pro X for making the sound clip to play in the speaker
- Reaper x64 for recording the hydrophone
- Spatial audio real-time applications (SPARTA) VST plug-ins for visualizing the movement created by Leo McCormack

Firstly, the team played a monotonous 880Hz sound to assure that the system works. The system managed to record the sound very well, but ran into problems when it has been tried to work with the VST plug-ins. There were difficulties for understanding the operating, but eventually the team started getting sensible results. The hydrophone array was turned around twice per try to validate the system's accuracy.

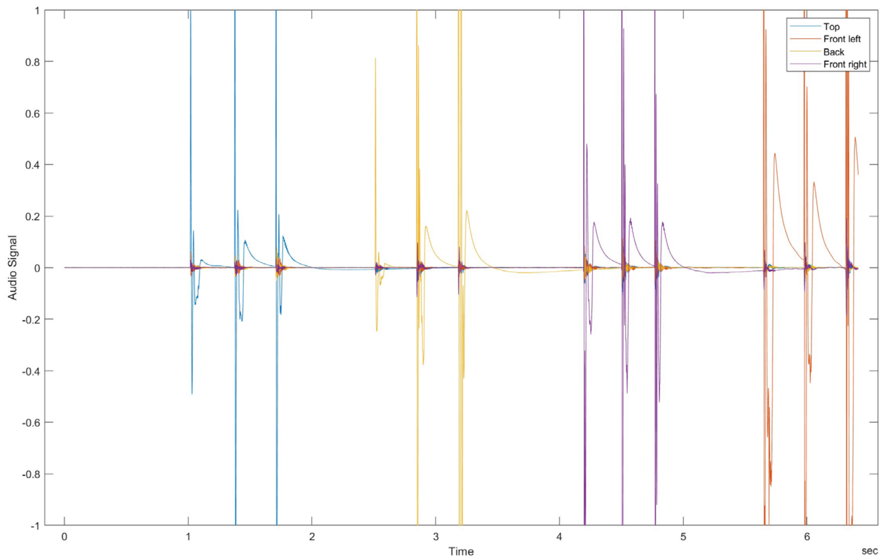


Figure 14. Illustrating recordings of the four hydrophones in MATLAB

The recording file was illustrated with MATLAB and it distinguishes the four hydrophone signals and shows them in their respective colours as seen in Figure 14. The recorded signal could be then further processed in MATLAB.

After this, the team created a 880Hz signal that varied on/off at certain pulses, up to the fastest impulses with a time interval of 0,125 s. This signal was played and recorded with hydrophones with a distance of roughly 3 meters. The recording simulates accurately the original sound and the pulses can be heard clearly. This indicates, for example, that the depth data could be encoded to the sound signal.

At the end of the experiment the team was able to learn and test the right operations needed to process the signal, the equipment and software useful to transmit and the signal.

Hydrophone sweeping test

A second transmission test was undergone the 1st of February 2019. Instead of the hydrophone array loaned from Aalto university, the team used a commercial hydrophone Aquarian AS-1, which was omnidirectional. In this experiment it was tried, if only one hydrophone would be enough to determine the direction of the sound source. The tests were done at the same pool, and the hydrophone was rotated and tilted sweeping the whole area with a jig made for this purpose.

The data gathered from the experiment was band-pass filtered and examined as seen in Figure 16. It was determined, that the sweeping method is too unaccurate for the diver localization application. Determining anything from the amplitude of the sound underwater is extremely difficult, as there is other noise as well and the angles become small when the diver is far away.

Figure 15. Test setup at the testing pool and evaluation of pulsating signal

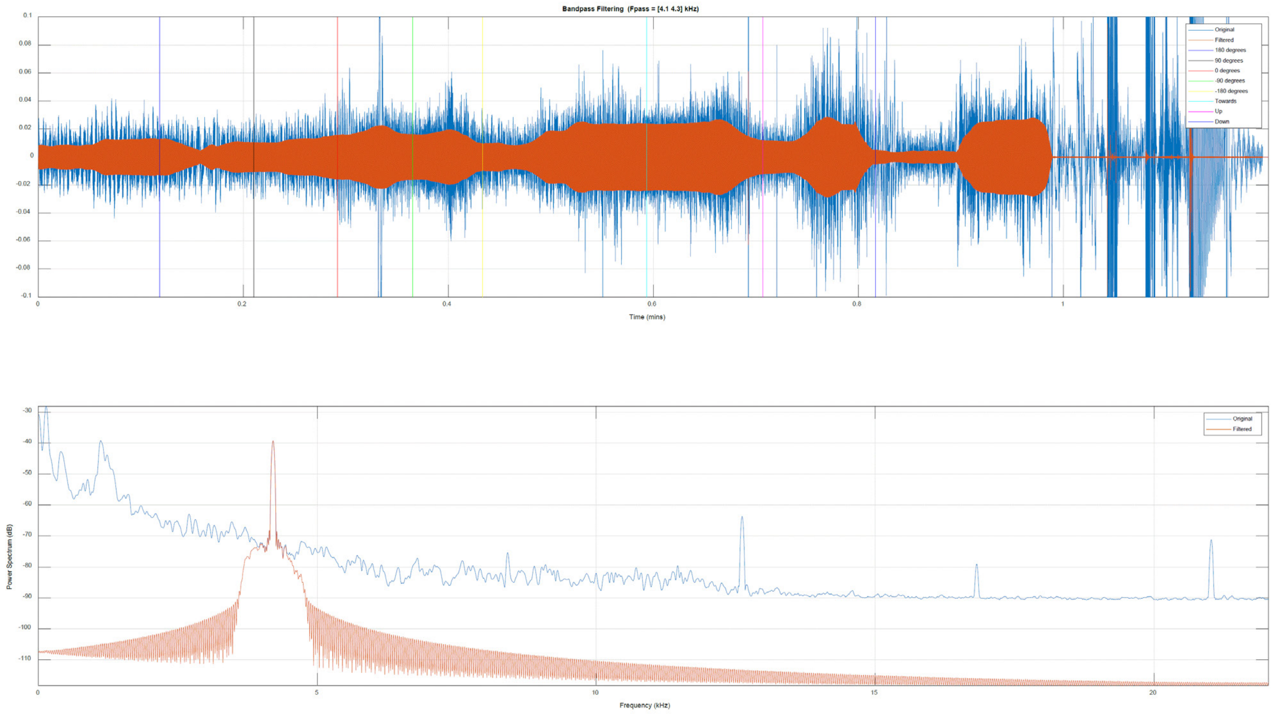


Figure 16. Sweep testing raw signal in blue and band-pass filtered data in orange

Environmental aspects

The effect of underwater hydro acoustic communication for the wildlife was also assessed by the team. Fundamentally for the diver localization concept, the aim was to establish a communication that exceeds the human hearing range, so over 20 kHz. It was learned, that most of the fish species communicate in much lower frequencies, but there are some species that might be affected by the sound waves. However, sonars act in the somewhat same region, so getting a qualification with diver localization product using hydro acoustics shouldn't be a problem.

Workshop for divers

Concerning the diver localization concept, a workshop was organised to better understand the needs of the users even better. The aim was to test the mockups of the physical products as well as the construction of the user experience.

Figure 17. Workshop ongoing in Aalto Design Factory

Participants and Activities

A group of 6 divers from Kupla participated in the workshop to share their experience. The structure of the workshop was based on role playing and examining the process. Several scenarios with different weather settings and personas were presented to the participators and each were assigned a role within these scenarios. The materials used in the workshop were the Seasu Kit mockups, dive equipment and scenario cards created for the workshop. Divers were also briefly interviewed to know their expertise in diving and get their development ideas for the project. Workshop was carried out in Aalto Design Factory Engine room.

Scenario Cards

Scenario 1

With the first scenario, the preparation of a dive was acted out using the participators' personal gear in order to observe and understand the overall process. This step was analysed to guide the designs of the products in the kit. Unexpected situations were also acted out to see what the Seasu Kit could help with in terms of regulations during emergencies.

A SUNNY DAY IN THAILAND, CLEAR WARM WATER

One operator on the boat: A bit lazy, his head is in the football game going on. He wants to read the newspaper about the game news.

One dive master diving with the other two less experienced divers. He is a tough master, expects a lot from his students and likes things to go smoothly.

One of the less experienced divers is a crazy daredevil that tries dangerous things, makes the dive master anxious and gets stuck in places.

The other less experienced diver is chill. There to learn, follows instructions, is cautious.

They are diving to a shipwreck. The ship is 15 meters below surface. They hover over the shipwreck and they have a clear view on where the shipwreck is. They start setting up the equipment.

1.They test the gear and check if it is working.

2.They do the matching.

3.They remove the surface unit from the dock and lower it in the water.

4.They put on the gear on their thin- one layer suits with no gloves and they jump.

5.They start descent towards the shipwreck when the crazy guy starts getting drifted a little bit.

6.The lady and the dive master do not know where the crazy guy is.

7.Dive master does not see the crazy guy again, this time he is stuck on some part of the ship out of sight.

8.They are coming back up.

9.They come back on the boat and automatically the device ends the dive.

A DAY IN APRIL IN FINLAND, NO ICE ON THE SURFACES OF THE SEA BUT QUITE COLD AND BLURRY WATER

One dive operator on the boat:Super careful following all instructions.

3 equally experienced diver friends taking a dip. They are all chill and content.

They are rediscovering a spot they had been to before, just doing an exploration and hobby dive. Today it is blurrier than last time so it is not helping that much that they know the area.

1.They test the gear and check if its working.

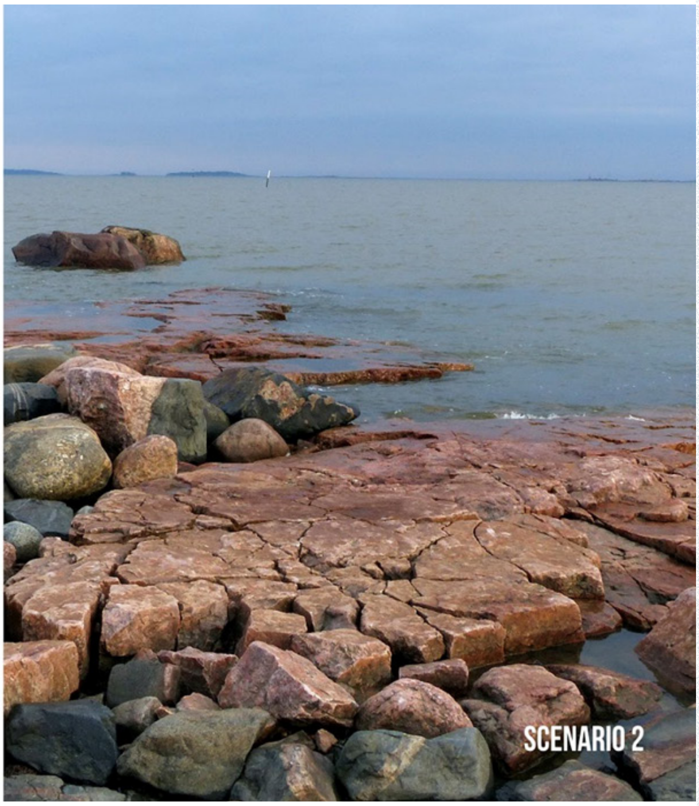
2.They do the matching.

3.They remove the surface unit from the dock and lower it in the water.

4.They put on the gear on their crazy thick scuba suits with their huge gloves.

5.They jump in and start descent. This is the point they realise it is much blurrier than the previous time. But they feel confident because they have the equipment.

6.All of a sudden, halfway into the dive, two drift one way and one of them drifts the other way. They all lost track of where the boat is also it is difficult to see further than 2 meters.



IT IS FEBRUARY IN SWEDEN, AND 2 DAREDEVILS ARE DIVING UNDER THE ICE.

A crazy guy convinced a crazy girl to dive under ice.

They have nobody on the surface to track them.

1.They have the Seasu gear that they took with them and they have placed it on the hole that they opened on the ice.

2.They start the sync of the devices on their phone with the app they have and they start the dive. They do not remember to test that everything is ok before starting the dive. So after they go a couple of meters, they come back to re-sync.

3.They resume the dive and at some point they are seperated and cant see each other anymore.

Figure 18. Mock-up on the wrist during a scenario

Scenario 2

The second scenario was created in order to understand the communication between the divers and the surface team in the case where a dive master is not present. Options for interaction between the users under the water and on the surface of the water were discussed to make the communication as efficient as possible. Here, the variations of message transfers were discussed and several options for short messages of warnings or information from the surface team were created.

Scenario 3

The final scenario was created to consider a different user group for the Seasu Kit in order to go through all of the options when finalising the business model. Through this topic, some potential options were added to the pool of target markets for the product. Additionally, the durability of the technology in harsher weather conditions were discussed.

Figure 19. Mock-up of the sound emitting unit attached in air tank

Outcomes

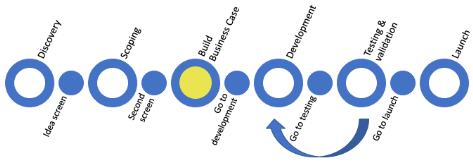
Learnings from the workshop were gathered in a table seen on the next page, but the main findings were as follows:

- The communication between the divers and the surface team needs to contain elements of short messages of warnings, general information and guidance
- The Hydrophone Array design must to be easy to transport and well protected

• The sound emitter must to be designed in a way that will be secured on to the tank and will not be removed after each dive. In needs to be a component that will be secured and fixed till the tank needs to be changed.
• The Dive Computer must have one command buttons for any request of actions as the suit and gloves used in some climates make it impossible to use a touch screen or smaller buttons.

		interface			product	business
		for dive operator	for dive master	for diver/s		
surface unit	hydrophone array	-battery/system status -on/off	X	X	-smaller -self balancing -no legs (maybe form of a ball, wouldn't ever get caught anywhere) -hang it from a buoy -if there is an emergency and the boat needs to move away or sth, it is a problem that the surface unit is hanging from the boat, it might get stuck on the propellers. also the current and the waves might move the product toward the propellers as well. -changing batteries -the system can me mounted on the hull or sth. a fixed installation might be considered. -if the surface unit is a stable buoy then the boat just circles around it without losing the location as well.	
surface unit	dive operator device	**-which is my dive team?** challange: how to seperate the right dive group from others when hovering over them if there are multiple teams using the same technology) **-mark the time that each diver went below the surface.** **-time remaining until agreed deadline**	X	X	-sturdy -some protection for pulling it back in case it falls into the water (maybe some rope) -	**the product can be rented by dive companies to sell "safer" dive experiences. The product can be used only among the people who own the product so if within a dive team a diver doesn't have the kit then there isn't a way of involving them in the match or nav trail.**
diver unit	speaker	X	-battery/system status -on/off	-battery/system status -on/off	-they will be attached to the tank and never be touched. -should be attached onto the side of the tank for sure	
diver unit	dive computer		-battery/system status -time remaining until agreed deadline reached -depth -maxx depth -presure in tank + tank pressure of all divers -messages: i am lost, i need help, lost buddy, lost dive master -distance, direction and depth of the buddy and the dive master -remaining time to deadline	-battery/system status -time remaining until agreed deadline reached -depth -maxx depth -presure in tank -messages: i am lost, i need help, lost buddy, lost dive master -distance, direction and depth of the buddy and the dive master -remaining time to deadline -"A drift warning is necessary telling the drifter he is too far from the group."-Additional information that could be useful while drifting is how much time the drifter has before resurfacing. Note: when sth goes wrong, the buddy is the first to know. So the dive master comes second in a situation where someone is stuck or drifting.	**one button command** for ease in situations of panic or when wewaring thick gloves.	

BUSINESS



In the Build Business Case phase the market potential for the solution concepts are considered. "Go to development" gate is passed by one concept. The business case can be refined still throughout the project. Because of the strict schedule and the nature of the project, "Go to development" gate is rather loose to reach the real prototyping phase quickly.

Go to development

For the "Go to development" gate it was decided to ask opinion from Saab's personnel. In collaboration with the sponsor representative the three concept proposals were emailed to about twenty company managers and experts. Most points from Saab scored the 3D diver localization concept and that was found as the most promising concept by the team as well. Team decided to develop a product that enables localization and communication for the diver

Business case building was ongoing parallel to the technological development since January to May. As part of the business case, the current products in the market were evaluated and so the focus for the development could be adjusted according to the observed market openings. In addition to the Saab questionnaire, a public survey was carried out to determine the customer needs and wants.

Users and customers

During the project the need for the product was found early on, but it was unclear who is the user. In the beginning the users included a wide range of divers with different needs and different willingness to invest to diving equipment. The Seasu kit is a investment that everyone does not want to make. It is crucial for the customer and the user that the kit has a different parts and it costs hundreds of euros. Everyone does not want to buy the whole kit. Also the Seasu kit works properly only if all the participants of the dive have the diver unit. It was concluded, that the product has two types of users: Active divers and non-active divers/new divers.

Non-active divers
Non-active divers do not want to invest to their diving equipment necessary. They buy the diving trips as a service from a club or a diving center. For them it is important that the diving is easy, safe and comfortable. This means that the Seasu Kit would suit for them well but they do not want to buy it. Therefore they are not potential customers, only users. However, they are potential as users, they just need the right channel.

Active divers
The second users are the active divers. They are willing to invest to equipment and they have their own equipment. For active divers own diving computers are extremely important as they collect data from the dive which is unique. Computers help the divers to plan their dives in the future based on the previous data. Active divers like to discover new diving spots and want to learn more about diving. They dive with a team of friends from clubs or diving associations, but they usually plan and make their trips without any external service. The active divers therefore are potential users and customers.

The kit is sold them in each part individually. This allows that the divers can buy the surface unit for their team and then the diver units for every individual. This way the customer get what they really need.

Diving clubs and dive centers
To really reach all our potential customers the kit is sold to clubs and centers. They can provide the equipment for their members. The kit makes it possible for differentiate from other operators in the business. However, there are only approximately 15 000 dive centers worldwide.

Stakeholders

Key stakeholders
Stakeholders are a crucial part of the value chain in the product. Seasu does not produce the components rather they have to be bought from a supplier. These supplier are important stakeholders as the quality of the final product is highly dependent on them.
To distribute the product to customers good channels are needed. The most important channels are different retail stores that focus on different diving equipment and online diving equipment store. In our survey 61% like to buy their equipment from a retail store and 27% from online store.

One key stakeholders are dive training providers. To spread the product to all new divers they must be taught to use it.

Possible partnership
The Seasu kits key feature is the localisation and diver communication. However, to work properly the kit requires a diving computer. Therefore to achieve as good as possible properties Seasu should not design or produce the diving computers rather the system should be integrated to some other computer. Possible partnership should be done with another company. Possible partnership companies could be Suunto or Oceans.io. Their diving computer would replace from the kit the diver unit attached to a hand. The partnership company could differentiate with our product and provide excellent diving computer.

Markets

Size estimate
As there are now mature or old markets for the product, the markets needed to be estimated based on other indicators. It must also be remembered that market for the product is totally new and necessary do not take part from the existing markets.
The amount of active and non-divers is relatively hard to estimate as there are no need for registration as a diver. The estimations of active divers vary from 3 million divers to 21 million divers. (*Edney, Joanne, and Dirk HR Spennemann. "Can artificial reef wrecks reduce diver impacts on shipwrecks? The management dimension." Journal of Maritime Archaeology 10.2 (2015): 141-157.)*

PADI (Professional Association of Diving Instructors) states that they have trained 27 million divers during their existence.

However the diving equipment markets has been valued to $3,731.4 million in 2017, and is expected to reach $5,106.7 million by 2025. (*https://www.alliedmarketresearch.com/diving-equipment-market*). The markets include all equipment related to diving, for example: regulators, vests, suits, swimming fins, navigation tools and diving computers.

Rivalry

The rivalry in the market is revised in the Figure 20 using Porter's five forces framework.

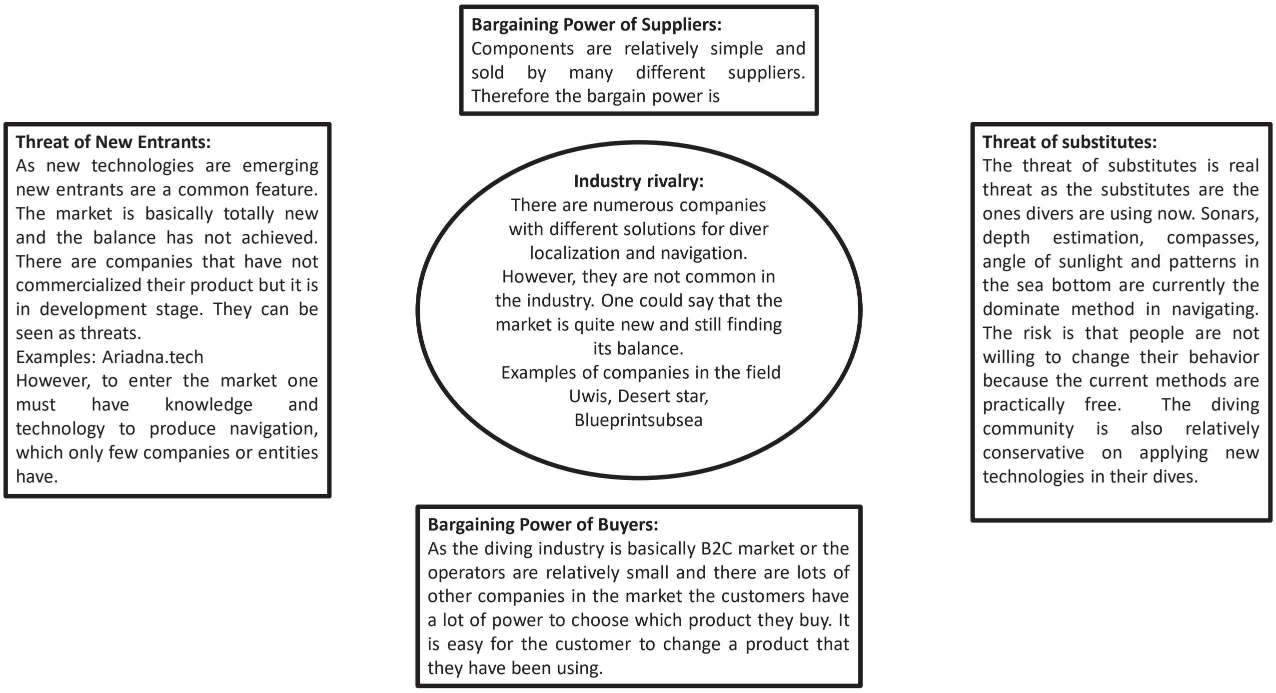


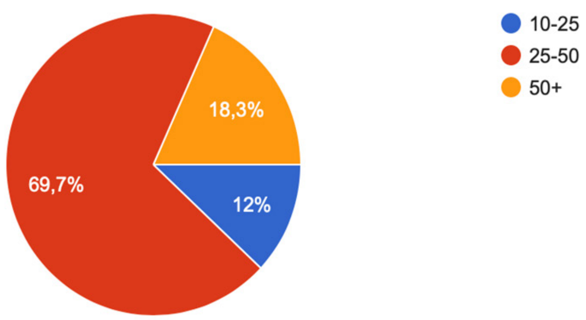
Figure 20. Evaluation of market rivalry

Survey

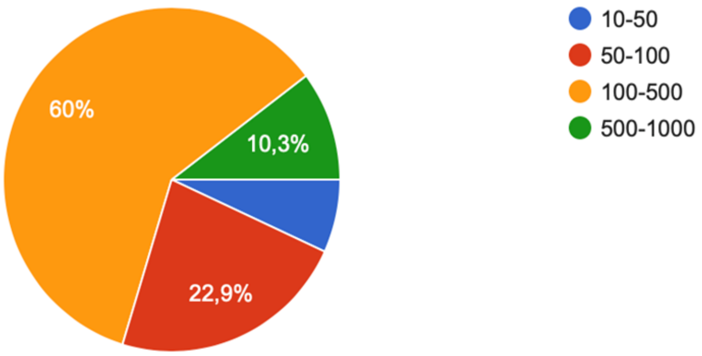
Survey answers

During the project a survey was conducted to understand the current customer behaviour. The survey was sent to two different finnish facebook groups. 175 divers answered to the survey. The results are gathered in the following charts.

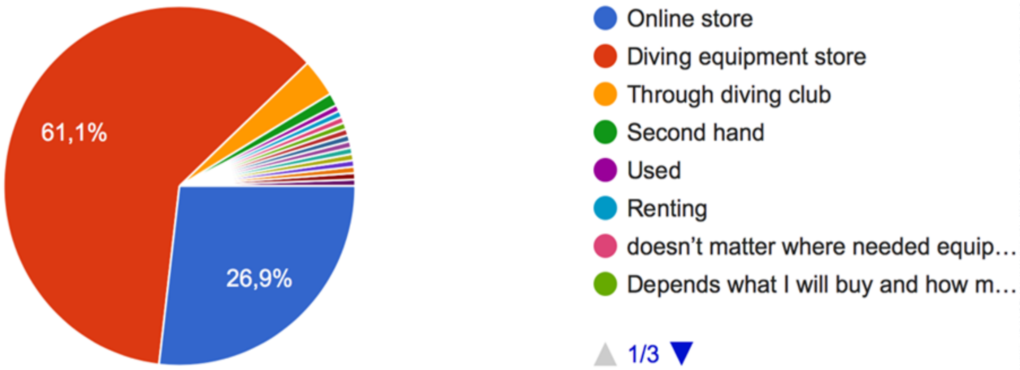
What is your age?



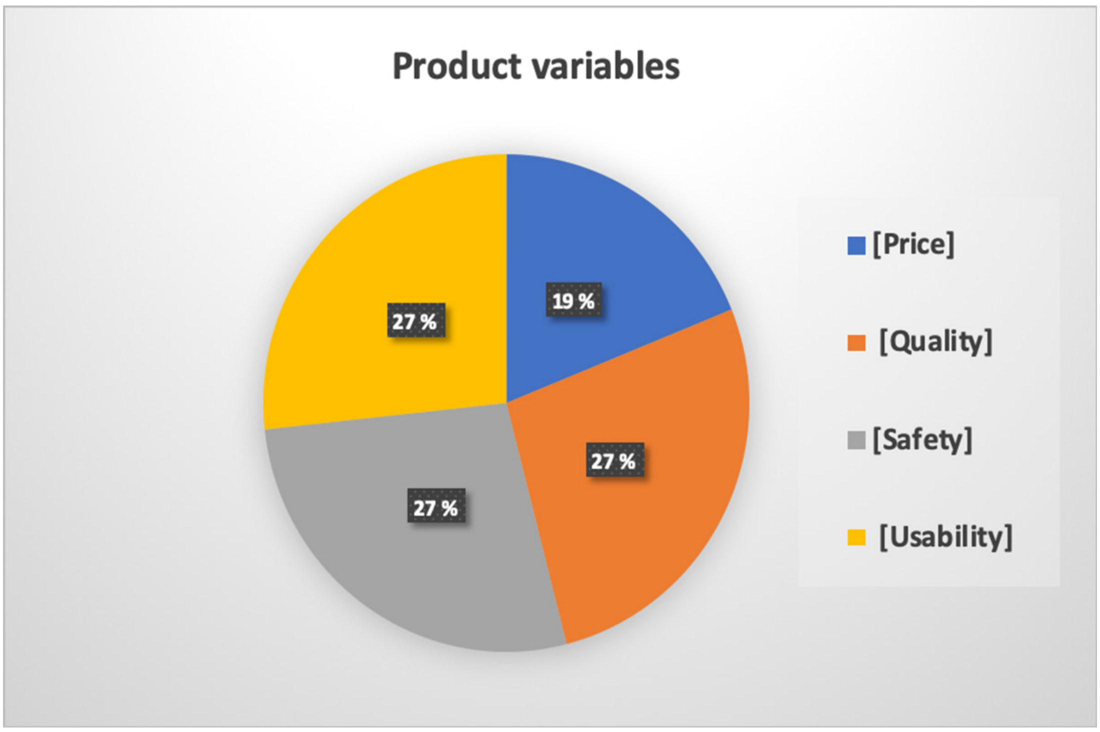
How much could you pay for specialized navigation equipment?



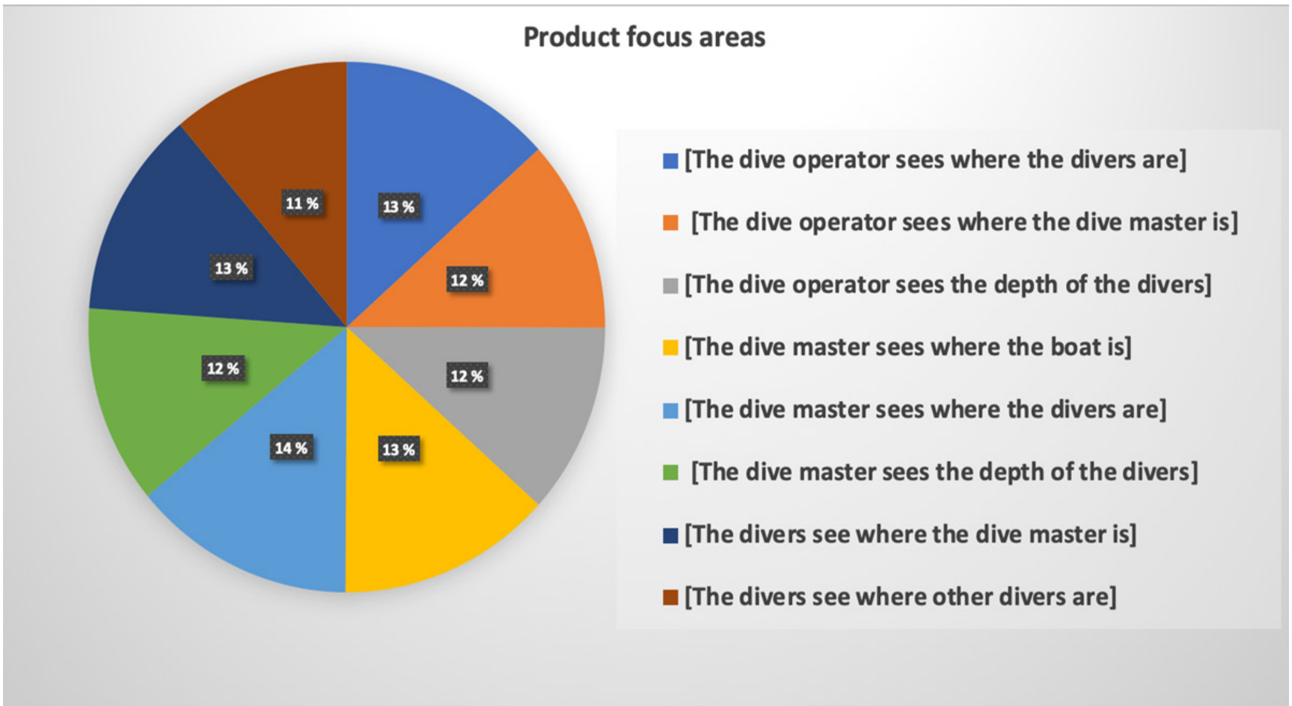
Where do you prefer buying diving equipment?



Which aspect do you value the most when buying diving equipment?



If you would have navigation device, which information would you value the most?



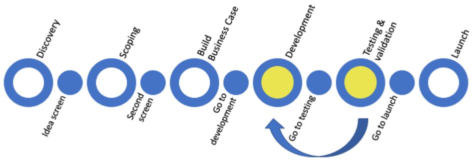
Survey conclusions

Crucial result from the survey considering our product is that most of people are ready to pay for diving equipment more than 100 euros. This means that the price point of the kit is approximately right. According to further discussions with divers, price increases the image of a safe product.

Also people mostly buy their equipment in online stores and retail stores. This means that they should be the main channels for the distribution of the kit.

The divers valued more the safety, quality and usability then price when choosing a product. Therefore safety, quality and usability should be in the core of the product. The goal was also to find out which aspects of the navigation the divers value the most. As one can see, there is not big differences between the focus areas. This led that the focus area had to be decided without real knowledge of the need.

DEVELOPMENT & TESTING



In Development phase, solution for the problem is designed further and refined. "Go to testing" gate is very loose, as the idea is to iterate the solution.

Testing&Validation is for putting the performance of the prototype to the test. "Go to launch" gate criteria are defined according to the initial concept requirements. The prototyping is an iterative process, so the development is done in multiple phases to reach the launch gate criteria.

Go to testing

As stated earlier, the development and testing was in this case iterative process. This is why these phases have been combined in this report also. For example the multiple hydrophone iterations were tested after building each one, and learnings were gained after each iteration.

Decision were made in this phase solely by the team. Experts in for example Aalto Design Factory were consulted during the process, but the design and testing was done by the team members. The most critical development parts of the project are presented in this chapter, starting from hydrophone design all the way to the app development.

Hydrophone design

First design
The use of piezoelectrical materials was crucial for the emission and reception of hydroacoustic signals. The piezoelectricity is the electric charge that accumulates in some materials in response to a mechanical stress applied to it. Using materials that undergoes such effect allows either the analysis of the mechanical stress by checking the electric charge generated or creating a mechanical stress by applying an electric charge on it.
The decision of using that kind of material led the focus on testing whether this could be done underwater and how would the behaviour and propagation of the sound emitted by the piezoceramics be. To test this, some requisites should be met:

- Since the users of the product would need to receive the signal from wherever they are, the emission as well as the reception of the signals should be omnidirectional. That means that the piezoceramics should emit and receive in every possible direction, or at least the largest angular range possible.

- As the piezoceramic needs to be connected to wires and receive or emit an electric impulse through them, they should be isolated from the water of the sea or lake where the dive occurs. Moreover, the material used to isolate it should propagate well sound waves.

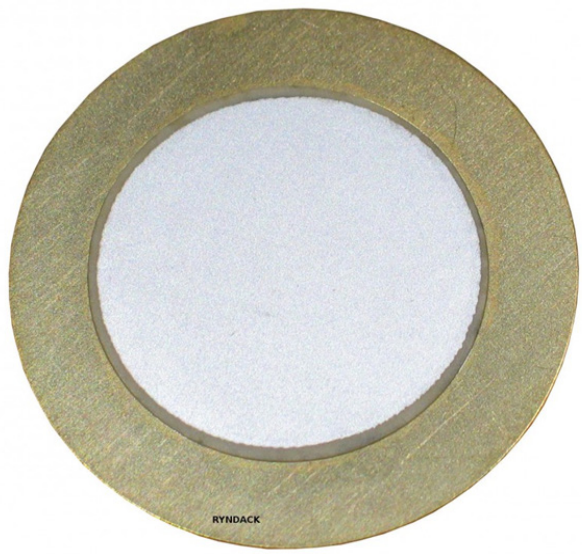


Figure 21. Planar piezoelectric ring

At first, due to the low cost and easy access to, planar piezoelectric rings such as the ones in Figure 21 were used to make a concept test, a DIY hydrophone.

An audio cable was soldered to the piezoelectric ring and it was inserted into a plastic deodorant lid and everything was sealed with silicon for the isolation. In order to ease the sound wave propagation, the lid was also filled with sunflower oil as shown in Image Y. The prototype is shown in Figure 23.
The hydrophone was then tested in a bucket filled with water and sound was recorded, but in a poor condition. This is because signals using the planar rings are better emitted

or captured in their axial direction. Which is why a unit of an isolated omnidirectional emitter and receiver of sound waves was then developed to follow all the mentioned requisites. There were two possible solutions, using the planar piezoelectric rings in a structure that makes it omnidirectional or a cylindrical piezoelectric material, which would capture and emit sound in both axial and radial directions.

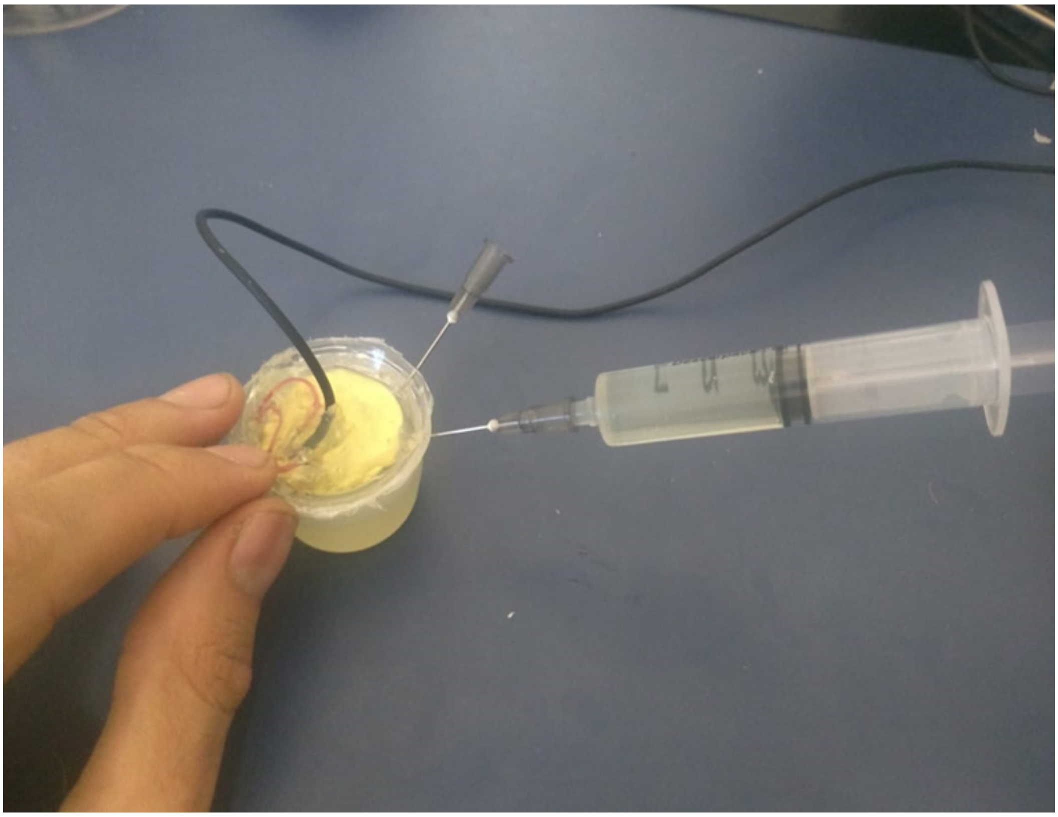


Figure 22. Sunflower oil being added to the isolated lid

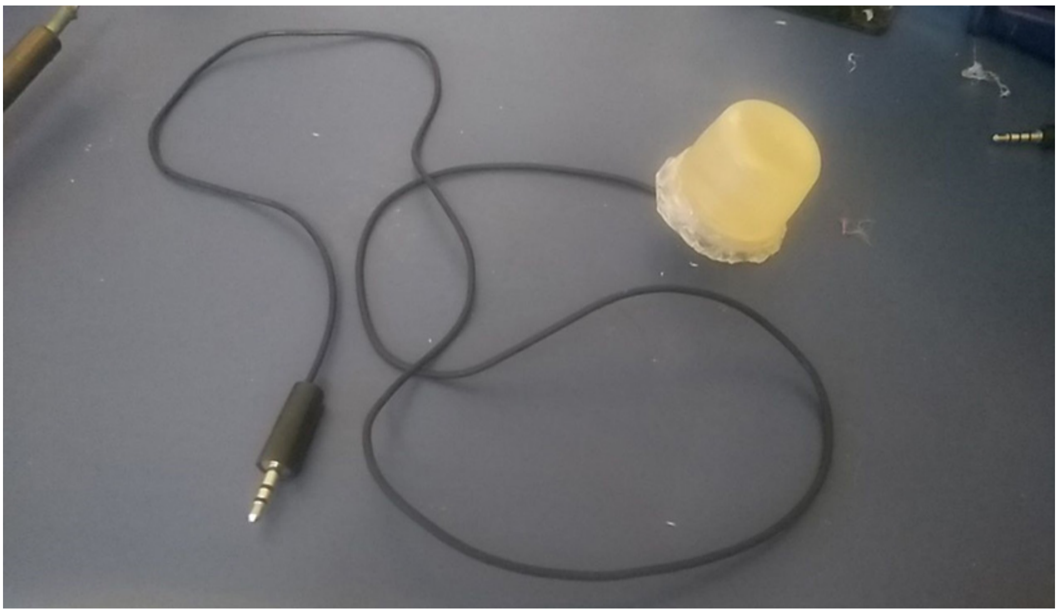


Figure 23. DIY Hydrophone

Second design
The cylindrical piezoeramics were ordered, but in the meantime the team tried to create an omnidirectional hydrophone with the material available. Four planar piezoelectric rings were attached together, fixed with an angular distance from each other, maintaining always the isolation from the water. This time the isolation was different, some disks were cut from acrylics in a laser cutting machine, the disks had radial holes in their outer diameter. Each planar piezoelectric ring was fixed in one of the disks inside of an O-ring.

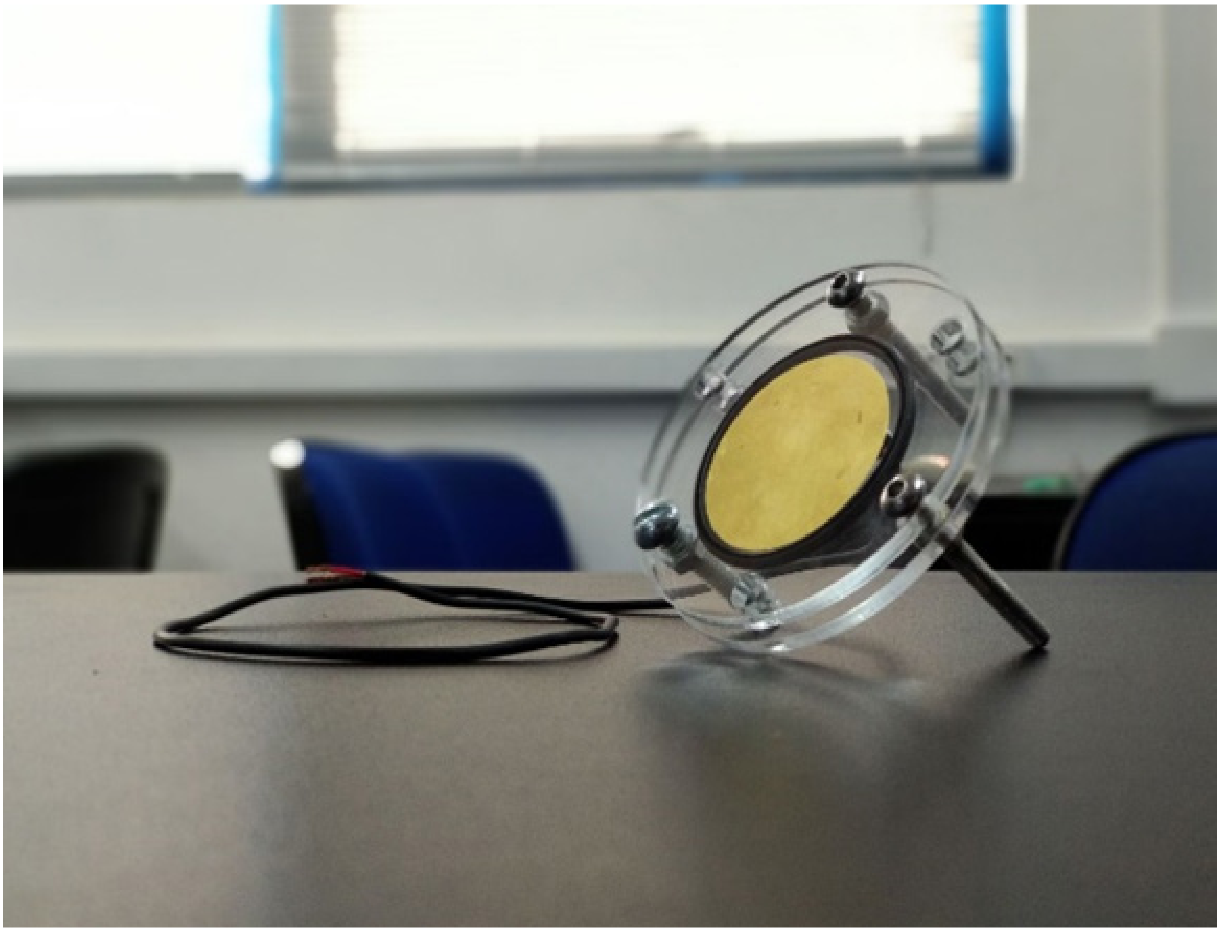


Figure 24. Acrylic isolation of the planar piezoelectric ring

The disks were then fixed in pairs, leaving the O-ring and the piezoelectric in between as shown in Figure 24. Each isolation was then angularly attached to the other one using a 3D printed part making a structure such as the one in Figure 25.

This structure has not been tested since in the meantime, the cylindrical piezoelectrics arrived and this structure was too big to be used in the hydrophone array with enough precision. However, this low-cost approach could be surprisingly effective for hydro acoustical applications, and could be examined further.

Figure 25. Structure that enables omnidirectional signals with planar piezoelectric rings

Literature was revised during the hydrophone design process, as it was originally far from anyone's area of knowledge. Most helpful articles for the designing and building hydrophone are listed below.

•BENSON, Bridget. Design of a low-cost underwater acoustic modem for short-range sensor networks. 2010.
•BAKAS, Konstantinos. CONSTRUCTION AND TESTING OF COMPACT LOW-NOISE HYDROPHONES WITH EXTENDED FREQUENCY RESPONSE. 2004.
•HACKATHORN, Michael. The Design of a Deep Ocean Hydrophone. 1983.
•GROVES, Ivor D. The Design of Deep-Submergence Hydrophones. 1971.

Third design

For the use of the cylindrical piezoelectric some study was made, and four papers were consulted to evaluate the best isolation method, the best piezo shape and type. Analysing the technical drawings of the mid-section of the designed hydrophones shown on the paper it is seen that the cylindrical piezo stays in the end point of the hydrophones and usually isolated by an aluminium tube. For this reason, aluminium rings were machined, as shown in Figure 26 and the isolation was made according to the Figure 27. Following also the logic of the second hydrophone design using acrylics, O-rings and bolts.

Figure 26. Aluminum rings being machined

Using this configuration, the hydrophones could be tested several times underwater with a great range and good precision, which allowed the testing and validation of electronics and other aspects needed as well as have proved that the transmission of signal and data underwater for greater distances was possible.

For the final hydrophone unit another design was created. For this design, the aluminum piece was extended to cover the whole piezoceramic ring on the frontside and to have a flange for attaching it to other components, as seen in the Figure 28.

Figure 27. Isolation of cylindrical piezoelectrics

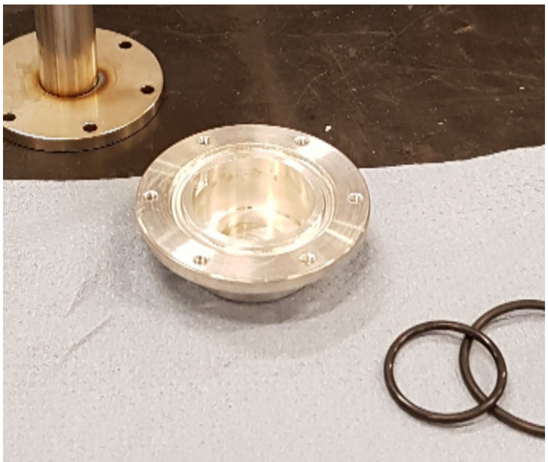


Figure 28. Final aluminum cup design

Hydrophone array design

First design
Having the single hydrophone unit available for underwater testing and validation, it was then appropriate to move on to the development of the whole array structure. For the array to work, four hydrophones should be in a specific distance from each other, forming a tetrahedral when considering only the hydrophones. The distance can be adapted by the code of the triangulation of the localization, but to make the array small and start the development of the code, the distance between each hydrophone was set to 200mm.

Also, in order to improve the propagation of the sound waves in the isolation, the acrylics was substituted by a single aluminium piece, as seen in Figure 28. This design considers that the electronics that needs to be connected to the cylindrical piezoelectric will be round and soldered in the inside of the cylinder.
Initially, the design was made considering a structure holding the hydrophones in the tetrahedral position and a body in the top of it to store the necessary electronics and to make the whole structure more stable underwater, as seen in Figure 29. The shape was inspired in a hydrodynamical form found in nature, the jellyfish.

However, since the piezoelectrics needed to be connected to the electronics, this hydrophone array design had the wires exposed, moreover it is fragile, heavy and hard to store, which made it be altered into a more compact structure.

Figure 29. First hydrophone array design

Figure 30. First hydrophone array mock-up

Second design

At first, the only problem noticed was the exposed wires and fragility, which led to some new design solutions. The most relevant ones, showed below in Figure 31, considered isolating all of the hydrophones in one single isolating unit, in a way that the wires and the space for the electronics would all be together, and another one considered using tubes to pass the wires through. Due to the possibility of the single isolating unit structure interfere in the reception of the signal by the hydrophones it was discarded and the tubular one was selected.

The structure using tubes in the last image was selected as a viable better option for solving the wire and fragility issue, although the trouble noticed now was the weight of the whole structure and the amount of unnecessary space available for the electronics inside the top body. This led the team to think of a more compact structure.

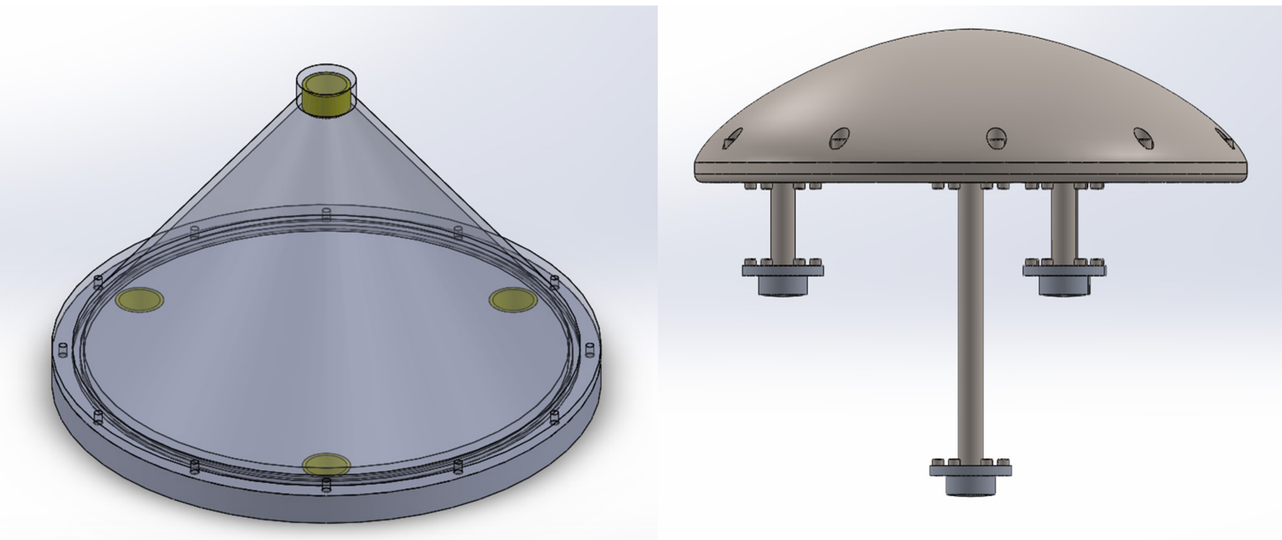


Figure 31. Two different hydrophone array designs for isolating all wires inside the structure

Third design
Inspired in the sp^3 hybridization of the carbon atom, or simply the structure of the CH_4 molecule in which the H atoms are organized in a tetrahedron and the carbon stays in the centre of it, a new design was developed in which the body that stores the electronics is in the middle of the hydrophones, making the tubes smaller in length and the body more compact. The body however was in the same plane as three of the hydrophones in order to ease the manufacturing process. It was also thought that the shape of the centre body could be a sphere as seen in Figure 32, but also due to machining difficulties that idea was left behind, making the design on Image Y the selected one.
These modifications to the 2nd Hydrophone Array design excluded the hydrodynamic body to make the structure more stable, which is why there was then a need for a stabilizing floater connected to the structure.

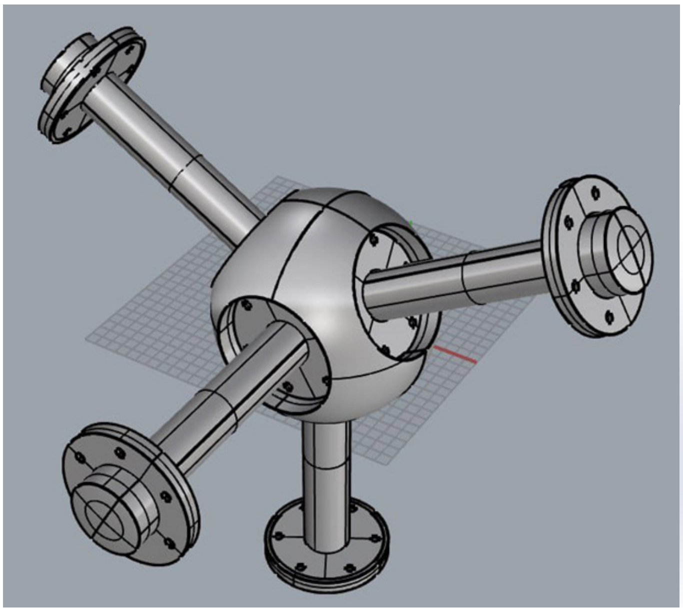


Figure 32. Array using spherical body

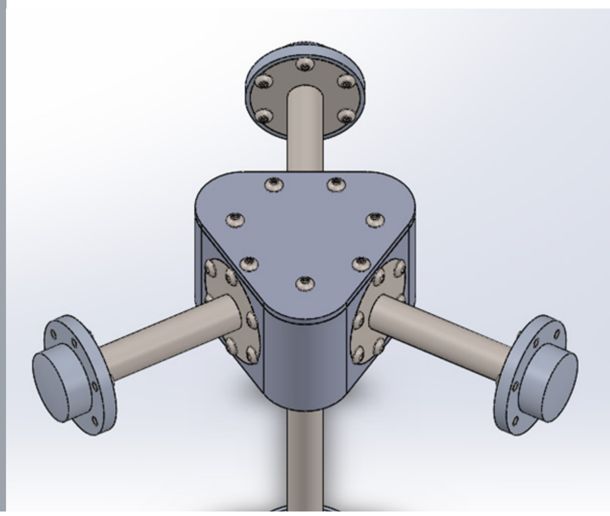


Figure 33. Array using simplified body

Overall details of the manufacturing process were then decided and some pieces and sizes were modified, such as the O-ring fittings, the fillet radius and the tube that was separated into a tube and to disks that were later soldered together. The final design was finally settled as in Figure 33. The center piece was machined from SikaBlock M960, because it is rather lightweight, easily machinable and still durable. The flanges and pipes were manufactured from stainless steel to avoid corrosion in sea environment.

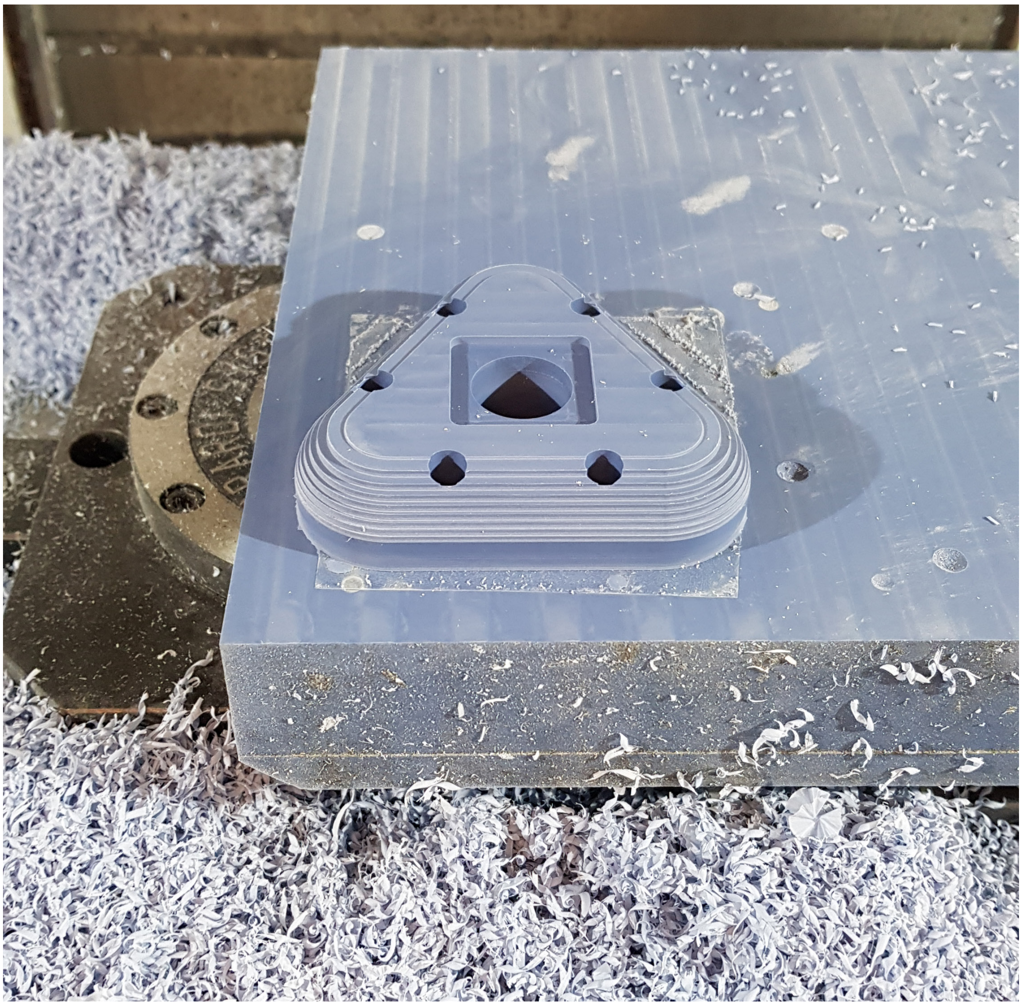


Figure 34. CNC-machining of the hydrophone unit lid ongoing

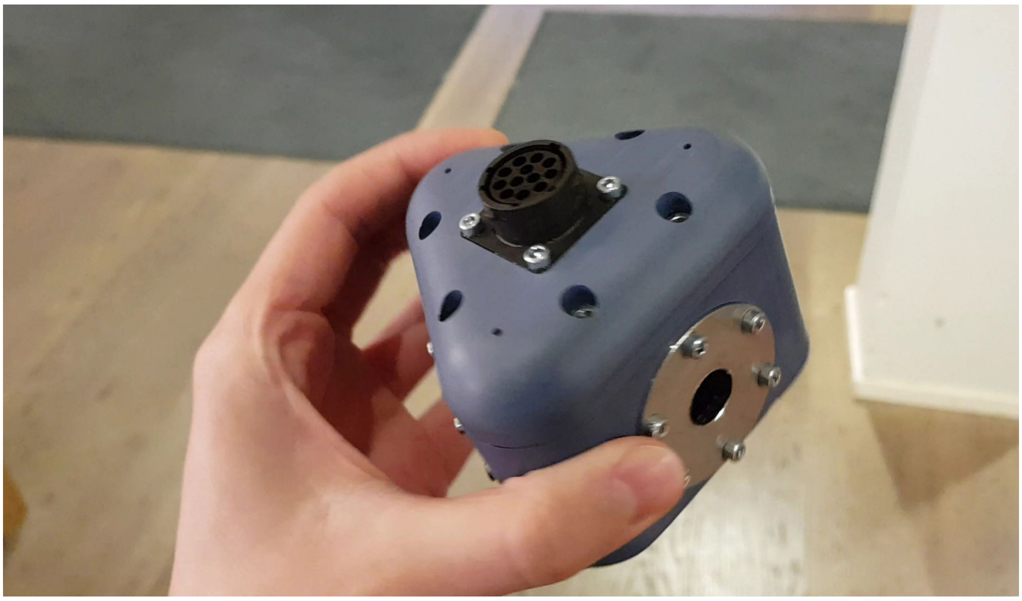


Figure 35. Machined hydrophone unit center piece with stainless steel flange and cable feed-through attached

Signal processing

Transmission
Taking into account that the sound source would be very close to the user and that the marine environment presents a lot of noise, choosing the right frequency to transmit is some crucial. Therefore, the diver unit would need to transmit on frequencies above the hearable spectrum (20 Hz to 20kHz) and avoid noisy frequencies caused by the environment and sea life as seen in Figure 36.

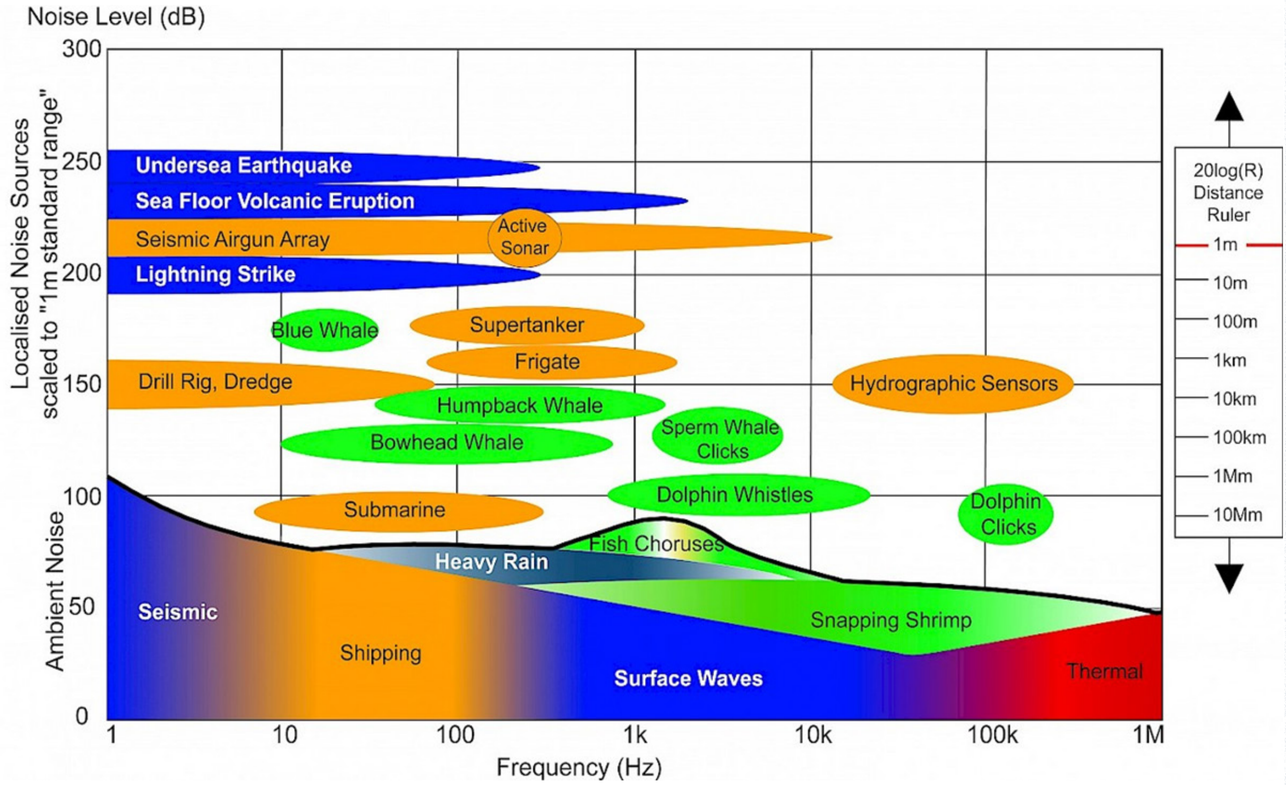


Figure 36. Underwater noise levels

In addition to that the frequency should suitable for both the transmitter and receiver device, the closer to the piezoceramic ring's resonant frequency (43 kHz) the better. Taking it all into consideration, a center frequency of 46 kHz was chosen.

To drive the piezoelectrics the power and voltage from the signal from the microcontroller needed to be amplified, to accomplish this an inductor in parallel to the output of a H-bridge was used.

Reception
The reception is divided in 3 main stages: amplification / filtering, signal demodulation, analog to digital conversion.

Amplification / Filtering
Firstly, the signal generated by the piezos would have to be amplified. However, only the specific range of frequencies transmitted should be amplified and every other noise should be filtered. To accomplish this, several filter and amplificator circuits were designed, simulated and prototyped, and some of these are shown in Figure 37.

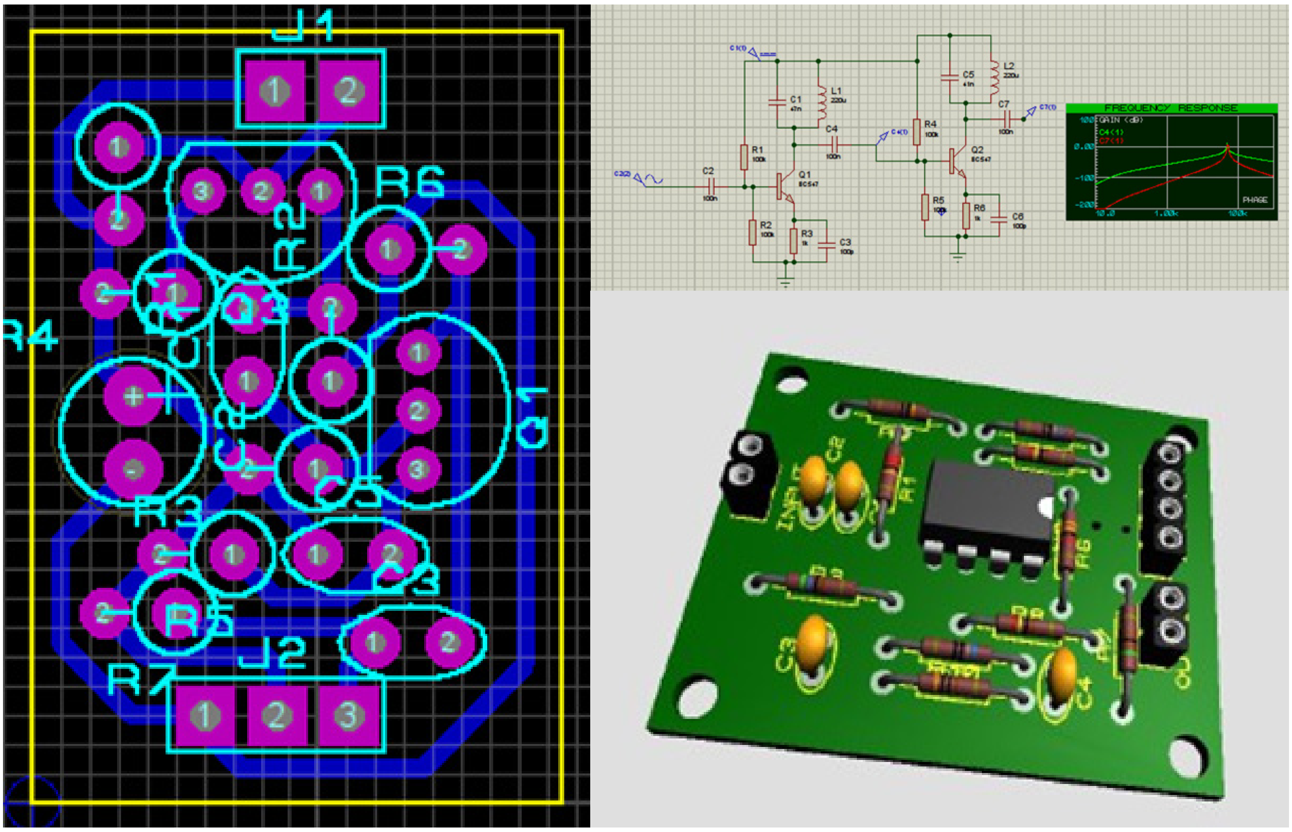


Figure 37. Design iterations of amplification/filtering circuit

After overcoming many self resonance issues, signal distortion, low amplification, low filtering and so on, the final circuit was defined as seen in Figure 38. The performance was verified with creating a Bode diagram, which is shown in Figure 39.

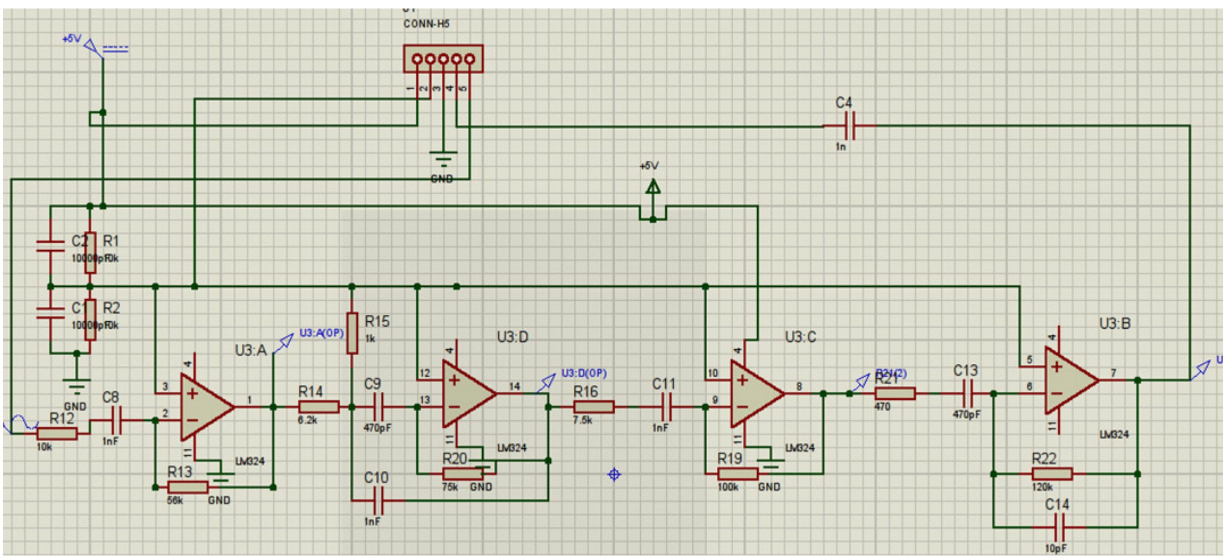


Figure 38. Final amplification/filtering layout

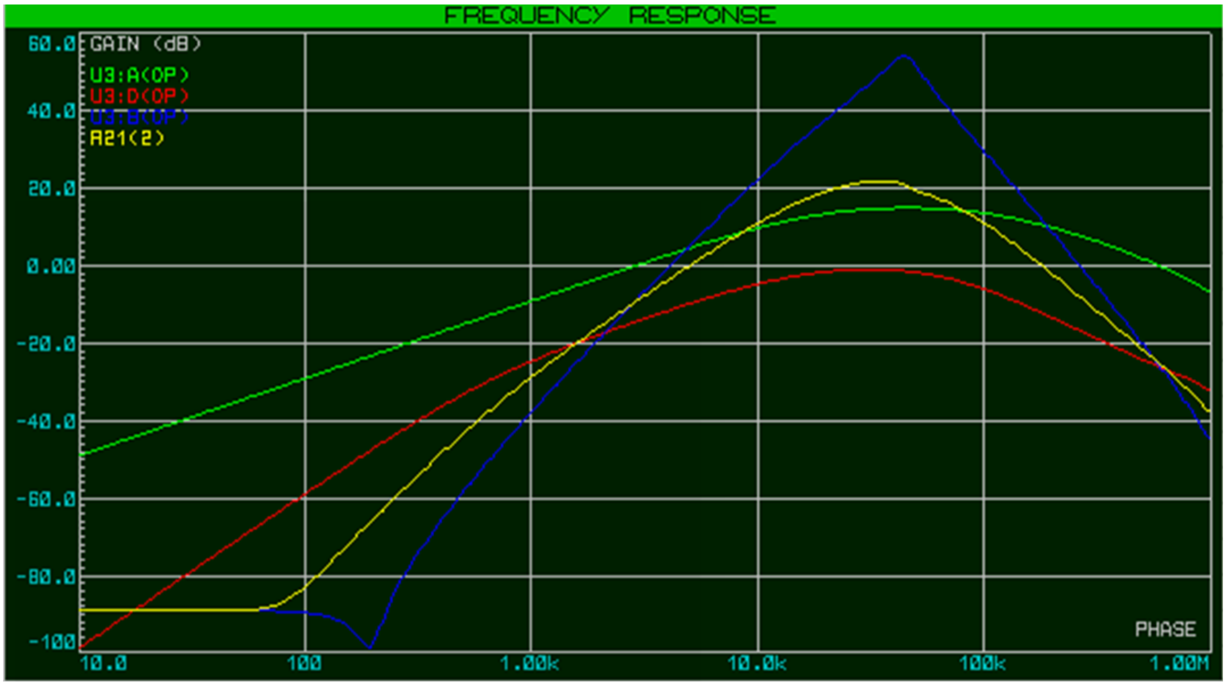


Figure 39. Bode diagram for the circuit, blue line representing the final design

Demodulation / Frequency reduction

The first idea was to use the Phase comparator followed by a low pass filter to reduce the input frequency and with that be able to use any audio jack receive the signal. This configuration reduced the signal frequency from 46kHz to 1kHz and at the same time kept the relative phase difference between each input intact, succesful signal transfer shown in Figure 40.

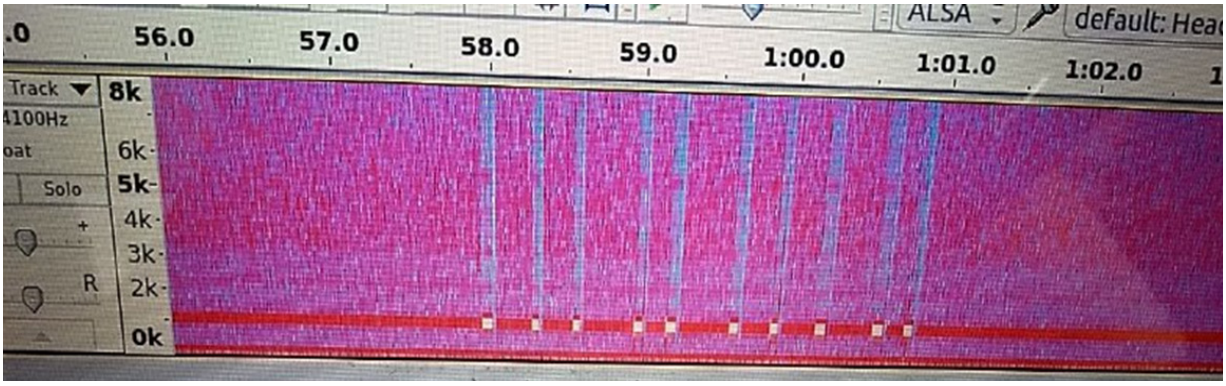


Figure 40. Received audio signal at 1kHz with test setup

With this setup the group was able to transmit text through a 40 meters lake with a concrete tower in the middle using only 0.25W of power and yet receiving a saturated signal at the output.

However, it was not possible to determine the starting point of each signal with the precision required. Despite been great setup for data transmission, it was not ideal to perform the localization.

The solution to this problem was to use modulated frequencies. The idea was to slightly variate the emitted frequency and demodulate it with Phase Locked Loop (PLL) after the

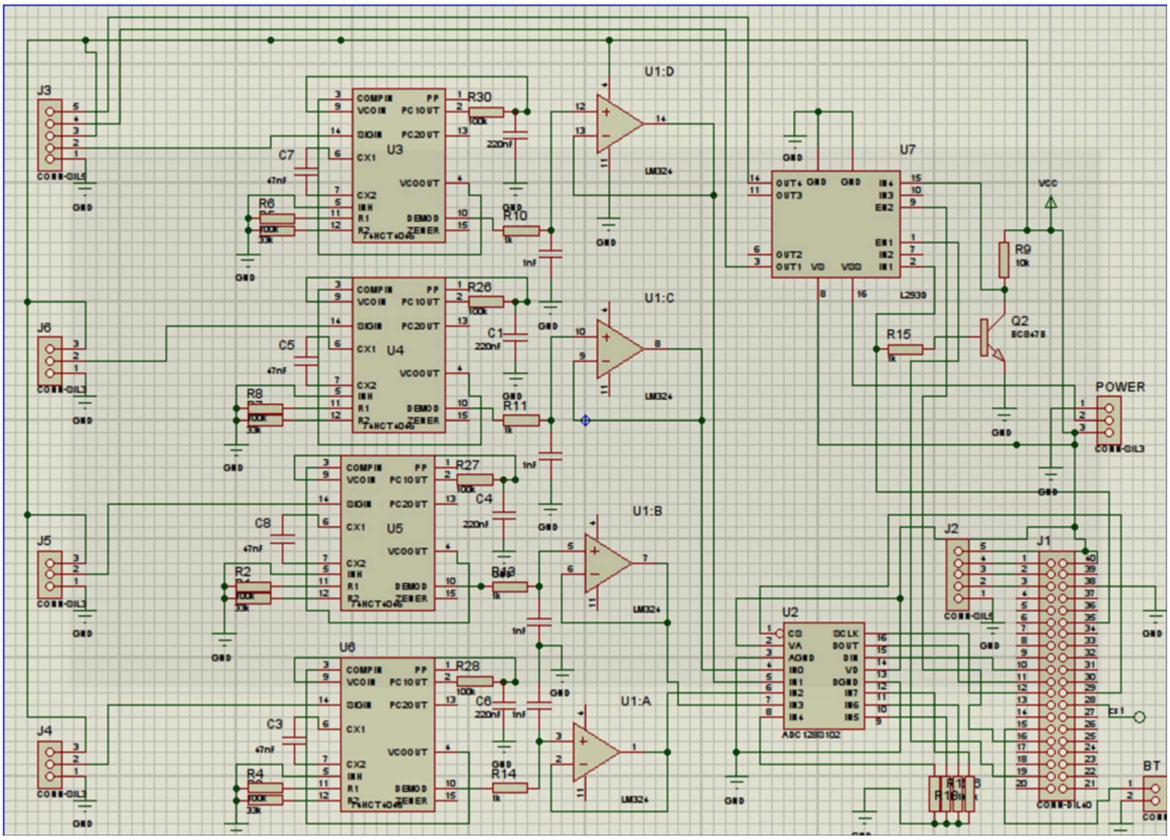


Figure 41. Final circuit diagram

amplification. By doing that it was possible to get a much more precise output and enable the transmitter to control the reduced frequency.

Analog to digital conversion

Two important factors must be considered in this step: the sample rate of analog digital converter (adc) and the resolution of each sample. To get a good phase resolution it was established as a requisite that the sample rate should at least 20 time higher than the working frequency and the sample resolution should be at least of 1024 bit. Because of that, and ADC chip of 8 channels, 4096 bits and maximum sample rate of 1MHz was used (adc128s102). The final circuit diagram can be seen in Figure 41.

Printed circuit boards

PCBs were acquired according to the circuit design. PCB design illustrated in Figure 42.

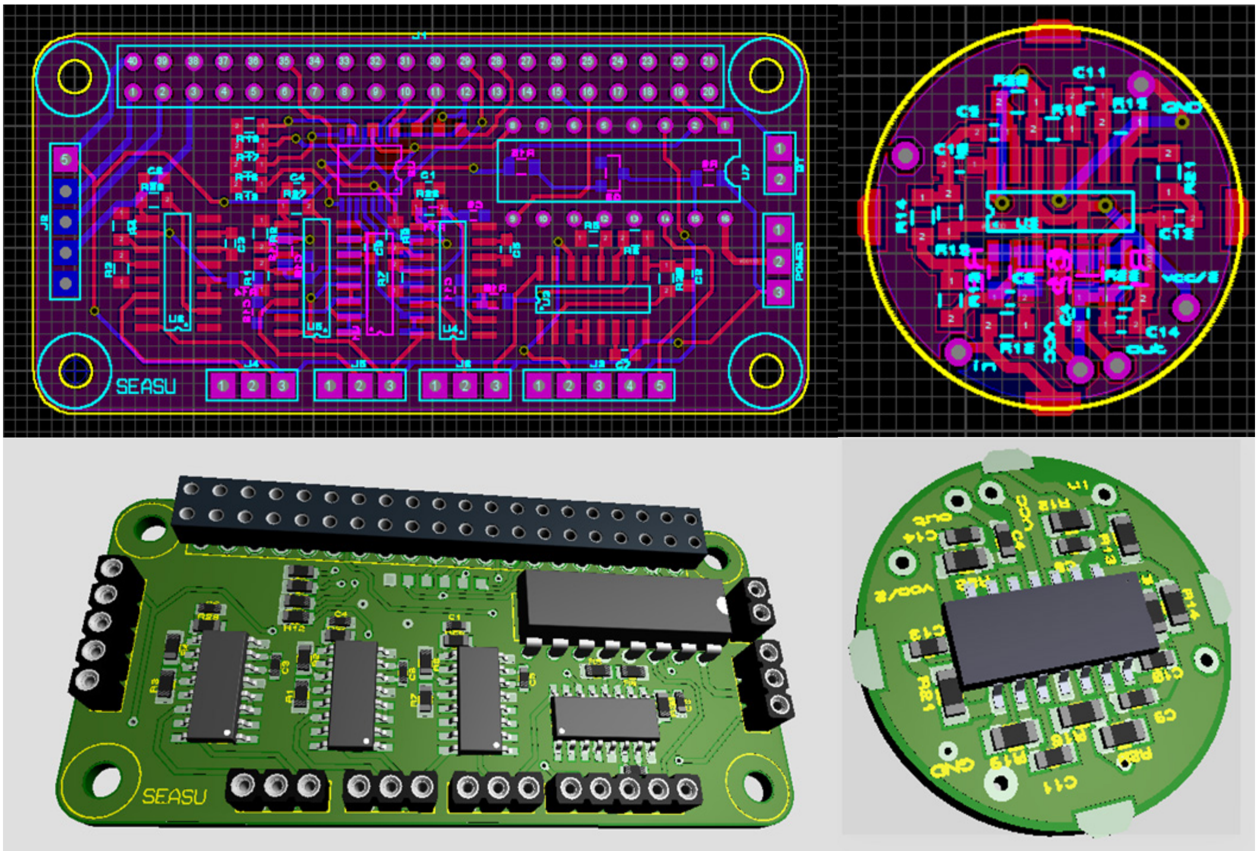


Figure 42. PCB design

Localization

Theory of localization
Naturally a mathematical model is required to be able to calculate the estimates for the diver positions. The team found out that research on diver localization had already been done at Aalto University. The research had only studied how to find out the direction where a diver is from a measurement position, but not the distance or the depth, but they had only relied on sound that divers emit while breathing and swimming. [*McCormack, L., Delkaris-Manias, S. and Pulkki, V., "Parametric Acoustic Camera for Real-Time Sound Capture, Analysis and Tracking," Proceedings of the 20th Internation Conference of Digital Audio Effects (DAFx-17), Edinburgh, UK, September 5-9, 2017*] By installing a sound source to a diver the data could be encoded to it and by combining depth data with the direction a 3D-location can be calculated.

The first idea was to use their written software to determine the direction of the diver, but after some research and discussion with the people behind the study, it was noticed that the model wouldn't work. The model requires that the wavelength of the received signal is longer than the distance between the receiving hydrophones. As the sound should be inaudible, the desired frequency to emit sound should be over 20 kHz and because the wavelength is inversely proportional to the frequency, the wavelength would become shorter than the physical dimensions of the hydrophones and hydrophones couldn't be installed close enough to one another.

After that dramatic shock the team didn't quit, but continued searching for other techniques to localize the divers. A lot easier model was developed inside the team that would be based on time of arrival differences. By knowing the time differences, distance differences can be calculated to each hydrophone. Then, using some simple mathematics the location can be calculated.

$$\sqrt{(x-x_1)^2+(y-y_1)^2+(z-z_1)^2)} = d + s_1$$
$$\sqrt{(x-x_2)^2+(y-y_2)^2+(z-z_2)^2)} = d + s_2$$
$$\sqrt{(x-x_3)^2+(y-y_3)^2+(z-z_3)^2)} = d + s_3$$
$$\sqrt{(x-x_4)^2+(y-y_4)^2+(z-z_4)^2)} = d + s_4$$

The equation group n the right represents a system with 4 hydrophones, where the x, y and z are the coordinates of the sound source and d is the distance from the source to the hydrophone that is closest to it. z also represents the depth of the diver and is known. The locations of all hydrophones are also known, and they are represented with x1 … x4, y1 … y4 and z1 … z4. The distance differences are represented with s1 … s4, one of which is always zero and they are determined before using the model and are thus known. That leaves only three variables, x, y and d, which means that the minimum number of hydrophones required to be able to solver the equations is only three. Using more than three hydrophones increases the accuracy of the localization, but simultaneously makes the equation group unsolvable, if the values do not match exactly. However, minimization algorithms can be used to overcome this issue. Such examples are Gradient Descent, Gauss-Newton, Levenberg–Marquardt and Nelder-Mead methods, which are widely described in literature. The common part for all these algorithms, however, is that they are slow and the time how long it takes to minimize the objective function, the equation group in this context, is unpredictable. Thus, they can be used to test whether the model works in a static situation or not and to verify the model, but they cannot be used to determine a location in real-time. The model was tested and verified to work in Matlab with almost any initial guess.

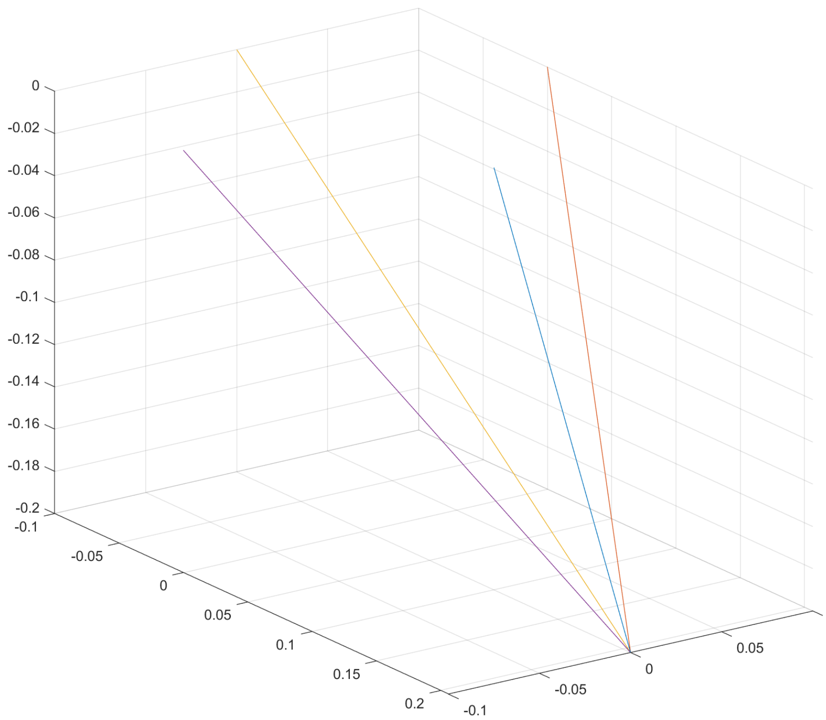


Figure 43. Testing and verifying the model in Matlab

Real-time localization requires the use of a dynamic model, which only computes a predefined amount of calculations on each measurement cycle. Such examples are a group of Kalman filters, for example. Since the model is nonlinear, which means that the output is not proportional to the change of input, the model needs to take that into consideration. Extended Kalman filter and Particle filter are ones, that work also with nonlinear models. They have two common principles. Each iteration consists of a prediction and update step. In the prediction, the next iteration's state, next location in this context, is predicted and then that prediction is updated with the sensor data, that has been fed to our mathematical model.

Fortunately, Matlab provides such models and the user only needs to give the parameters, such as the objective function and an initial guess for the model to start with. Matlab also includes a toolbox to generate C code that microcontrollers can run, meaning that most of the difficult mathematics and programming didn't need to be defined inside the team.

Localization can be made more accurate by including a temperature sensor to the hydrophone array. Since the speed of sound depends on water temperature, the localization would be more accurate, if the temperature of the water close to the hydrophone array is known [*https://www.engineeringtoolbox.com/sound-speed-water-d_598.html*]. The water temperature elsewhere doesn't matter, since the model doesn't depend on the speed on which the sound travels before it hits the first hydrophone.

Fundamentally, Seasu kit calculates the location of a diver with two variables:

- Direction of the sound
- Depth of the diver

The direction of the sound is obtained from the time difference the sound wave hits the hydrophones in the hydrophone array. Depth of the diver is found out with a pressure sensor that is integrated in the sound emitting unit. This depth information is conveyed to the hydrophone unit by encoding in to the modulated sound signal. This method with the exact depth value obtained from the diver itself is more accurate than methods that are based to the measurement of time it takes for the sound signal to travel from the emitter to the receiver.

Signal processing

To process the signal and do calculate its issuing position, a small, power efficient and versatile single board computer (SBC) should be used. The "Raspberry Pi Zero W" is an cheap and well documented SBC and, as it presents all the required feature, it was the chosen platform.

In order to calculate the position of the diver unit, it was necessary to extract reception time delay of each hydrophone from the raw data. To do that the group firstly focused on determining the presence or not of a signal, to than work on extracting the time delay.

Initially, a "discrete fast fourier transform"(dfft) implemented in Python to create a dynamic spectrogram of the input signal. With that it was already possible to detect the presence of a signal and even translate its serial content into text. But, this approach requires a lot of computing power it was taking a lot of time to process each sample, making it impractical for a real time application. The second attempt was to use a Goertzel Filter, that works like an dfft for a single frequency. It definitely reduced the computing time but it was not enough yet. To overcome this issue, the group developed from scratch an C- extension for python that applies a Goertzel Filter. This extension reduced the computing time by a factor of 100, finally making it viable to use on the Raspberry Pi.

With the signal detection completed, the group started developing the code to extract the time delay. Firstly, a simple peak detection as was implemented, although, on account of some signal distortions and remaining noise, the precision of the measured time delay was far from the one required. After spending some days on trying improve this method by applying different filters and tweaking several parameters, the method was discarded.

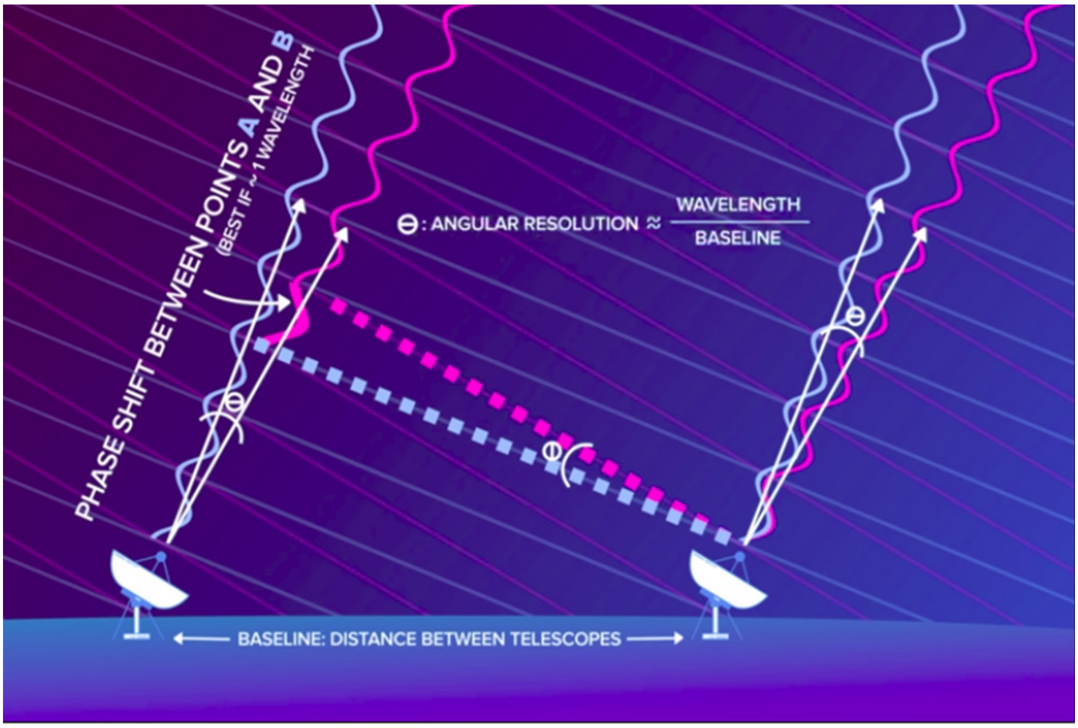


Figure 44. Interferometry principle illustrated

Ater a lot of research and brainstorming, the group developed a new extended version of the interferometry method. The interferometry basically consist of collecting and measuring the spectrum phase of the received signal on two or more points in the space. Knowing the wavelength of the signal, it is possible determine the arrive angle comparing the received phase on each sensor. This principle is widely used on quantum physics experiments, astronomy and was even used to generate the first black hole image, as illustrated in Figure 44.

On our case, the wavelength (λ) of the signal on water was much smaller than the distance between each hydrophone (d), so theoretically this method would not do much for us as a measurement would represent a signal possibly coming from head(d / λ) different angles. In addition to that, as proved on the first algorithm tested, it was not possible to overcome this problem with a direct measurement of the time difference.
The solution was to use modulated frequencies. with that, it was now possible to precisely control the wavelength of the data signal and consequently esure that d / λ is smaller than 1. Furthermore, this method allows us to refine the calculated time delay by variating λ.
Considering the time restrictions of the project, this algorithm could only be tested on a two dimensional plane using only 2 receivers on air.

Initially, a modulated frequency of 2 kHz and the PLL demodulation setup was used in the setup. With this, the phase of each received wave could be precisely indentified (+-0.2 rad) the movement of the soud source was properly translated to the phase difference. The results turned out to be very promising, proving the concept of the algorithm and the demodulation step.

Orientation sensing
Hydrophone array can and will change its orientation while floating in water. Thus, even if the direction of the signal is being transmitted is known, it doesn't help, if the hydrophone array will change its orientation all the time. By knowing the orientation, it can be taken into account in the mathematical model and the array does not have to stay still.

It was also discussed to try to stabilize the array to a fixed orientation. But since the components required by the orientation sensing are relatively cheap and in mass production the development costs for mathematics and programming are negligible, implementing the fixed position is far too costly and would significantly decrease the potential profit margins of the product.

There are three angles that define the orientation; pitch, roll and yaw. They are illustrated in Figure 45. Pitch and roll angles can be detected by using just a 3-axis accelerometer, but yaw angle requires also the use of a 3-axis gyroscope. Instructions and model for calculating all the angles were adapted from [*https://www.instructables.com/id/MPU6050-Arduino-6-Axis-Accelerometer-Gyro-GY-521-B*].

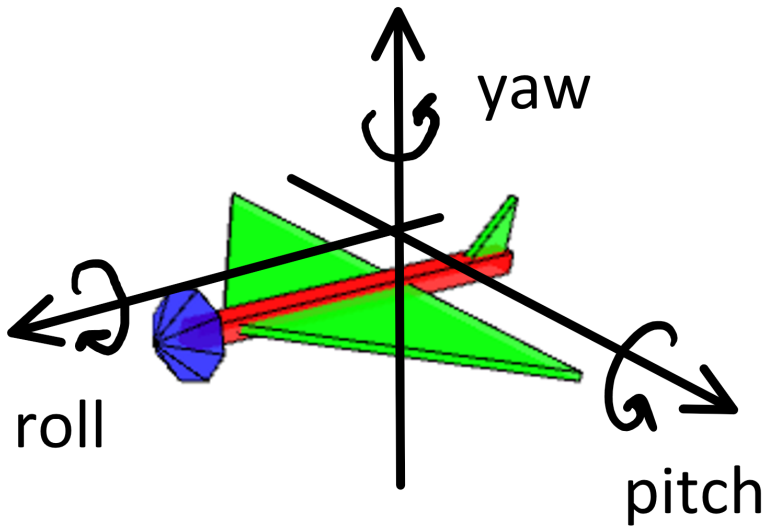


Figure 45. Angles

However, it was noticed in testing that the error for the yaw angle grew too much over time and wasn't accurate enough for the purposes of this product. After research it was found that including magnetometer data into the model would be able to produce more accurate results. That required, however, the use of more sophisticated mathematical models, but the required algorithms were fortunately found online. The algorithms in the model are thoroughly discussed in [*https://se.mathworks.com/help/fusion/ref/ahrsfilter-system-object.html*].

For the accelerometer and gyroscope GY-521 was chosen, as it has a MPU6050 chip, that includes both of those sensors. Magnetometer was chosen to be HMC5883L. These chips were used due to their low price and great availability.
Orientation sensing could naturally be improved by using more accurate sensors, but that would increase the production costs. Another improvement would be to accurately calibrate the sensors. Even though some calibration was done, calibrating them more accurately wouldn't cost significantly more in the long run and would be a viable option to enhance the accuracy of the orientation sensing and eventually the localization of the divers.

App

Android app development

The locations of the divers as well as messages to be sent and received need to be visualized to the users in real-time. A natural selection nowadays is a mobile device such as an Android or an iOS phone or tablet. Those were selected for this purpose as well, which meant that an app or a web page needed to be created and since the network at sea or lake might work poorly or not at all. Thus, an app was the only viable solution, because it only requires an internet connection when it's being downloaded. For the prototype, Android was chosen, due to the fact that it is far easier to get apps allowed by Google than Apple.

Then the app needed to be developed. Outsourcing the programming was discussed, since the team had zero experience on Android programming, but it was decided that the app would be built by ourselves. One of the reasons for that decision was that the requirements of the app were always developing, meaning that outsourcing would have been difficult as constant contact would have been needed to discuss the ever-changing requirements. Second one was that there was interest in the team to learn to do it and the team already knew the principles of software engineering and had experience on several previous software projects.

App was written in Java using Android studio. Several online tutorials were needed to get the process going, as Java and Android development had to be learnt. After those the main parts of the development went smoothly. Part of the success in development was due to the fact that version control and sharing the work was done straight from the start using Git.

App wasn't made by just team's programmers, but also other members of the team took part in designing the layout and defined requirements as how the user would interact with the software. That allowed some to learn the first steps of software engineering as well as helped the programmers to concentrate on their part since they didn't need to define the requirements by themselves.
The program itself consists of separate front- and backend, which is the norm for most user interfaces. The layouts of the different views could be done by one person, while other one designed the logic behind each individual view. The layouts are defined in xml files while logic is written in Java. There are also other configuration files related to Android, which define how one can return from one view to the previous one, for example. The different views in the app have been illustrated in Figure 46.

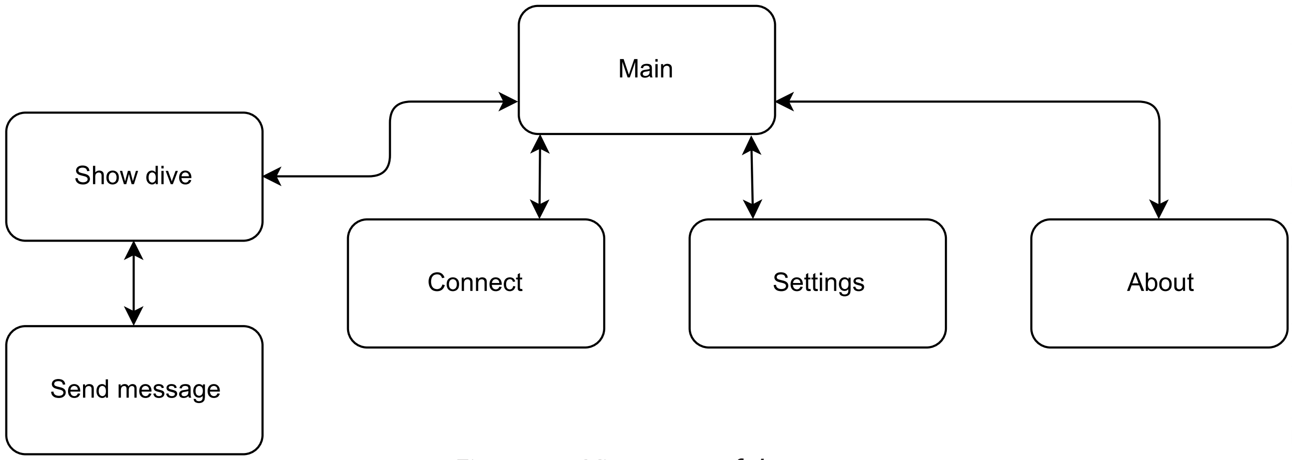


Figure 46. View map of the app

The "Show dive" view of the app is the one that visualizes the locations of the divers. The boat is initially located in the center of the screen and the divers are drawn with circles. They circles are drawn in different colours to allow the users to distinguish the divers from one another. The depth of each diver is shown in meters in the center of each circle. There are also circles with increasing sizes drawn from the center. Their purpose is to indicate the distance on sea level. That can be chosen by the user, but in every case the distance in meters is indicated next to each circle. The users can also pan and zoom the screen and the locations of the distance indicators are switched to another axis if the user zooms out from an area where they are initially drawn. Sending of the messages can be done by clicking the diver to which the message is desired to be sent. Also, sending the same message to multiple or all of the divers is simple to implement, even though it wasn't done to the prototype. The view is illustrated in Figure 47.

Commercial aspects were also considered. Since the app also required some graphics, they were either designed by the team or collected from sites that allowed commercial use. Thus, further development wouldn't need to suffer from breaking copyright laws and all the current graphics could be used in commercial product.

There are numerous ways how to improve the app, as it has been developed merely to just illustrate the concept. For example, it should be programmed to work in other platforms as well, especially on iOS. One could also write tests for the software to improve reliability and to be able to know more certainly that the requirements have been met. It would also help in further development and ensure that the quality requirements have been met. At the time of writing this document the program has just been tested on people, but as it hasn't been presented to a larger audience, which means that unwanted behaviour unfortunately wouldn't be surprising to happen. Also, proper documentation and software requirements specification (SRS) should be written to ease further development.

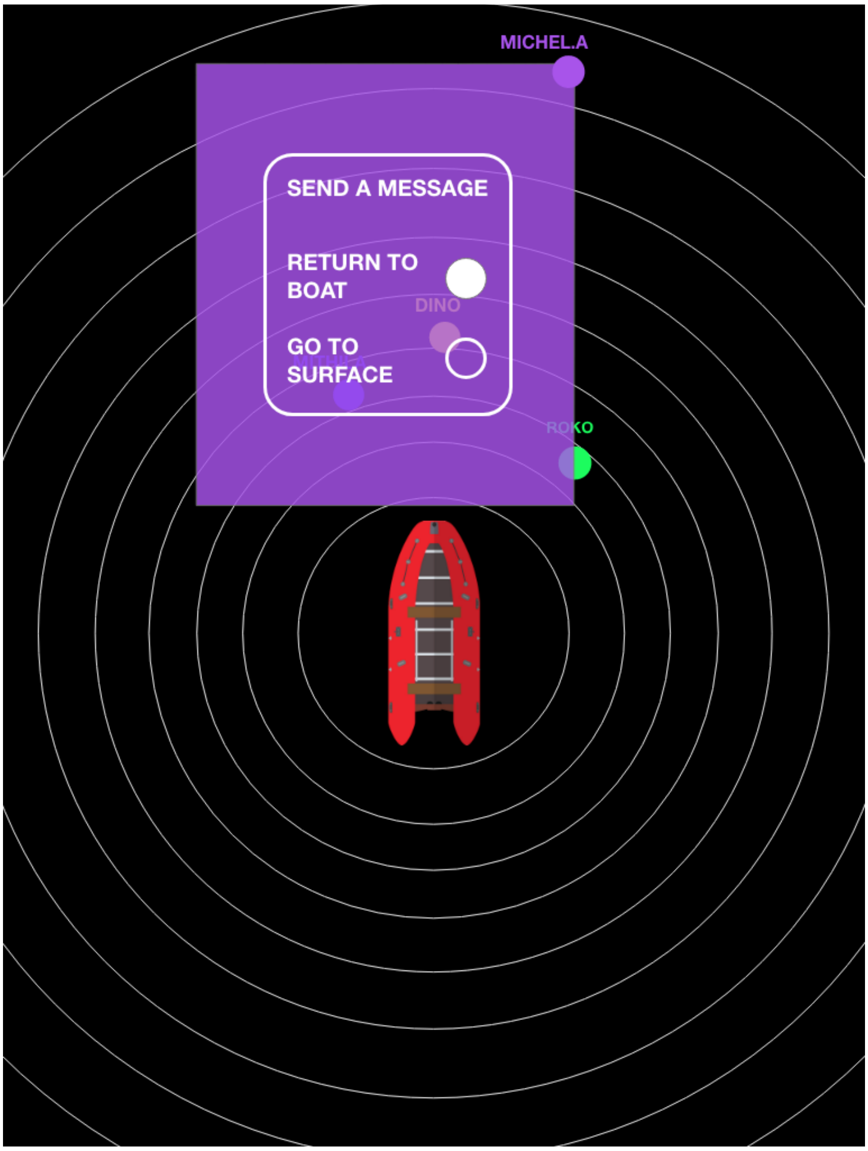


Figure 47. Message view of the app

Communication with surface unit

The surface unit and the mobile device need to be able to communicate wirelessly. Since the microcontroller of the surface unit was chosen to be a Raspberry Pi Zero W, it allowed the use of either Bluetooth or WLAN, both of which are integrated on the chip. Bluetooth was chosen from those, as almost all mobile devices include a Bluetooth chip nowadays and the communication didn't require high speeds and preferred lower battery consumption.

The connection was established in a way that the mobile device works as a client, which connects to the Raspberry Pi that has been set up to be a server. Firstly, they must be paired and only after that the connection can be made. Then the connection is open, and data can be sent and received. The pairing and connecting were made to be able to perform in the app so that the UI would be more intuitive to use, since they wouldn't need to exit the app to establish a connection.

Surprisingly long development was required to get the connection to work properly. While one could simply have gone to the settings of a mobile device to establish the connection, one still couldn't send data from the app. Performing the connection in the app simplified the transfer process significantly. Instructions and an example used in developing the connection were [*https://developer.android.com/guide/topics/connectivity/Bluetooth*] and [*https://github.com/googlesamples/android-BluetoothChat*].

There are multiple ways how to improve the connection of the product. From user interface side it would be easier to use if the connection could be made automatically to previously connected devices. That is also simple to implement, but it was left out, because it wasn't needed in testing nor in to be used in final gala.

Another improvement would be to increase the range of the communication. If extreme distances are needed, Bluetooth isn't viable as even it can only reach distances up to hundreds of meters theoretically. In practice it's usually ten or less. [*http://www.bluair.pl/bluetooth-range*] While Bluetooth is perfectly fine for prototyping purposes, fully commercialized device should make use of other radio frequency communication lines. Known alternatives are, for example, GSM, 2G, 3G and even satellite connection. They could maintain the connection even if the surface unit is left far away from the connected mobile device (device on boat on most cases).

Satellite connections would allow the communication basically from anywhere around the world, but they would increase the costs significantly. Other mentioned alternatives would require to be able to connect to a built network, thus leaving the user to rely on Bluetooth. However, there are standards, that are able to transmit data over dozens of kilometres inexpensively and without a need for any extra infrastructure. An example of those is LoRa [*https://www.loriot.io/lorawan.html*] and that would be perfect alternative to Bluetooth in this product.

Thirdly, Bluetooth Low Energy (BLE) should be used instead of regular Bluetooth. As the name implies, BLE would consume significantly less power, which would extend the operational times of the unit. It could also be used to reduce battery sizes, leading to smaller devices overall.

Stabilization of hydrophone unit

Connection to boat

The surface unit must be attached to the boat in a way that is not dangerous for the equipment. In order to avoid the surface unit or the hydrophones to hit the boat or the thrusters, it has been decided that they should hold in a still position, in one side of the boat, with a rigid connection. One of the possible connection can be a telescopic pole, whose ends are attached on the boat and on the surface unit.

As the height of a boat is unknown, the team decided that the device should be 2.50 m long, at least. On the internet, there are many manufacturers available for the supply of telescopic poles, which enable on the first side to reach long distances, on the other side to occupy a little space when the system is kept onboard.
The main development targets were the interfaces of the ends with the boat/surface unit.

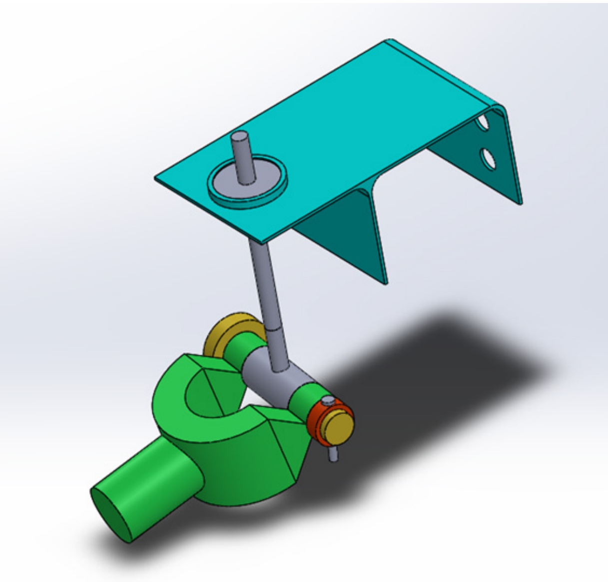


Figure 48. First connection iteration

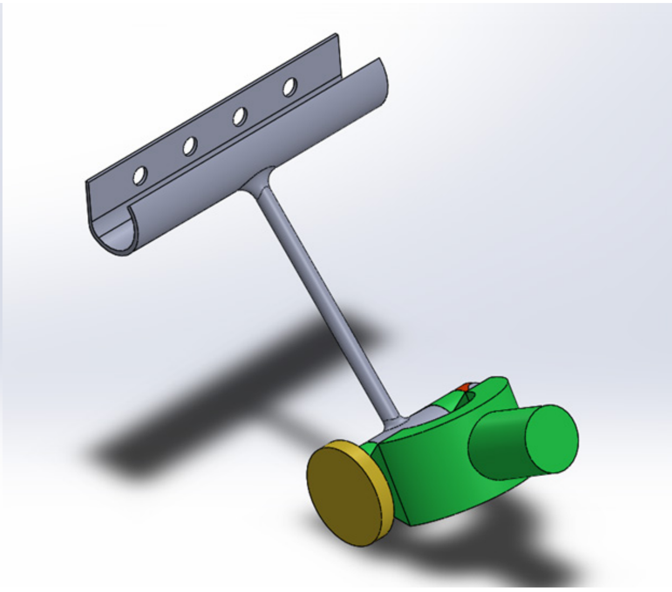


Figure 49. Second connection iteration

A first issue to solve is about how to fix the pole on board. A first solution was to make it grip through bracket clamps, shown in Figure 48. This solution includes two parallel surfaces, and is the same that is used to attach the trolling motor on the transom. It is suitable in the case of attaching the pole at flat surfaces, with parallel walls. An intrinsic problem is that the telescopic pole is forced to stay in vertical position; therefore, this solution is feasible if the position of the surface unit is far enough from the vessel's bottom edges.

Another solution is to use a round bracket clamps to hold the pole to the ship, attached to the poles of the boat pulpit. In this case, a configuration should allow us to change the angle between the surface and the pole just rotating the clamp. Therefore, in this case even a normal pole, not telescopic, could work. The diameter of boat pulpit is generally one inch or 7/5 inches, so standard diameters that could allow us to use circular clamps of those dimensions.

Being inspired by those considerations, another solution has been thought. It is composed of a screw system that allows the on-board system to be attached to the boat's pulpit, no matter what its diameter is. The solution is shown in Figures 49 and 50.

Figure 50. Boat connection prototype

Testing of stabilizing shapes

The purpose of the test about the stabilizing cage was to test the hydrophone array's dynamic behaviour under the water, for different shapes. The aim was to evaluate what was the relationship between the shape of the hydrophone array and the oscillations, assuming it physically connected to the surface unit. In fact, the ultimate purpose was to establish what shape was the most suitable in order to reduce oscillations and stabilize the whole system.

Testing

The system was composed of two main actors: the cage, which was the hydrophone array mock-up, and a lifebuoy ring, which simulated the surface unit. A thin rope connected all the pieces together. All the pieces were 3-D printed, therefore the material is PVC and the density is less than the steel. Three shapes were tested for the floating cage:

Flattened Semi-hemispherical

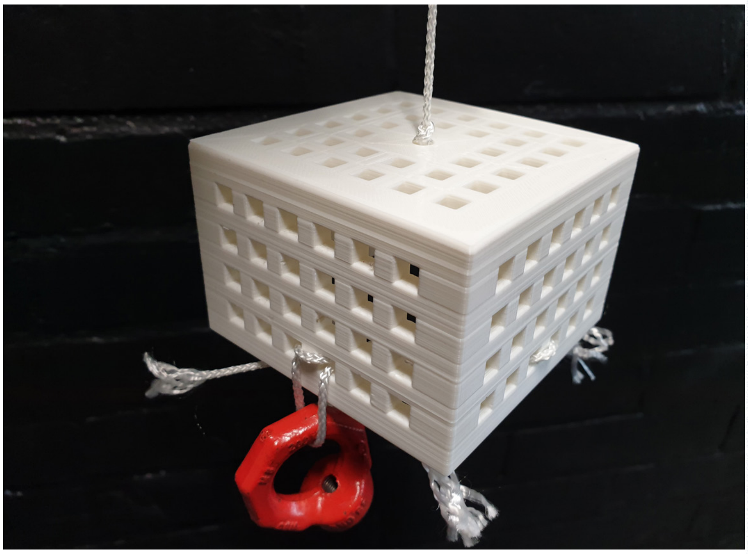
Walls 0.5 cm thick, characterised by multiple rectangular holes through all the directions. Being 3-D printed, it had problems with precision and removal of supports layer, which led to a low quality result, but it has been decided to test it anyway. It measured 20 cm of diameter and 5 cm of height.

Semi-hemispherical

Walls 2.5 cm thick and two rows of hemispherical holes circularly repeated all around the surface. This is a simpler and smaller version of the previous one. It measures 15 cm of diameter (externally).

Parallelepiped

Walls 1 cm thick. It is characterised by 15 cm of length, 15 cm of thickness and 10 cm of height. It is deprived of one of the squared bases. In a modular way, each side is characterised by squared holes, of the dimensions of 10 cm per side, far 1.2 cm from the adjacent ones.



The surface unit has been mocked up with a common lifebuoy ring. All the pieces were weighted down by big bolts – four for each piece – that had the function of dragging the floating cages under the level of the water. A rope that was the only connecting material of the entire system connected the floating cage, the bolts and the lifebuoy ring.
The environment for testing was a hot tube rented in the Design Factory of Aalto university, which was large and depth enough to lead the tests.

The test has been led by one member of the team that pulled, through the wire, the lifebuoy ring, which dragged automatically the floating cage connected to it. The floating cages were alternated easily, through a system that allowed easily the changing of the topology of cage. The evaluation of the result was considered with sight: the member of the team had to establish how the object fluctuate underwater during movements of the whole system.
The simulated movements were made in two ways: the first one was the horizontal movement, simulating case of the movement of the boat; the second one was vertical movement, simulating the act of the waves.

Results
The semi-hemispherical, flattened cage responded badly to the oscillation, as the big dimension increased the viscous force effect on the side and tended to turn upside down the cage. Moreover, the system seemed to be characterised by instability, as small repetitive movements increased the system oscillation.

The semi-hemispherical and parallelepiped shapes behaved, surprisingly, similarly. In fact, both of them stayed stable even with the largest and more impulsive movements, balancing the underwater unit after the first disturbance. It showed, therefore, that small pieces, characterised by a low aspect ratio – the characteristic dimension of the base on the height are more balanced than big, flattened shapes.

The different shapes were considered for the hydrophone unit, but the manufacturability of complex shapes was raised as an issue. Also, some shapes would block the sound waves reaching the hydrophones in the array. All in all, this testing can be used in further development, when functionalities of the product are figured out and proper manufacturing method, for example metal 3D printing, found.

Hydrophone unit and surface unit connection

When the design of the hydrophone array can not be stabilizing in itself, it had to be made sure that the connection to surface unit would diminish the oscillations as well as possible. The connection must be not rigid in order to reduce the oscillation of the hydrophone array, if the surface unit moves on the surface. The team decided the system to be composed of stainless steel wire rope. The main problem is how to connect the ropes with the hydrophone array and the surface unit.
The chosen idea was to attach the wire through a loop as seen in Figure 51.

Figure 51. Wire loop

FUTURE DEVELOPMENT

The concept of 3D diver localization gained lots of positive attention during the project. It was concluded that it has market potential, after a customer group is specifically chosen and aimed at. In addition, the messaging enabling hydro acoustic communication method has potential to carry all kinds of data. By being able to transfer data underwater fast, many new application areas arise. Some of the most obvious future development areas are listed below.

Reducing size
Smaller microcontrollers and batteries could be introduced and so the size of the components significantly reduced

Enabling two-way messaging
A more comprehensive diver unit interface could be designed, enabling the diver to send custom messages for the surface team.

Enabling target locationing
With system integration, the diver unit could guide the diver to a pre-specified target. The target could be set for example with the Android App.

Integrating diver units
Design a watch unit, that acts as the emitting and the receiving unit. Challenges in this are the size and the extensive development work to compete with current dive computer functionalities. These functionalities include for example saving dive data and wireless back-up of data.

Collaborating with current dive computer manufacturers
Some dive computer manufacturers use low range underwater wireless communication on their watches. If the diver sound emitting unit could communicate with commercial dive computer, the best features of both could be utilized.

Removing the boat connection
If the surface unit was emitting the data via satellite, the unit wouldn't have to be close to the boat. However, new methods for keeping the product in place would have to be made,