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Niko Kyyrönen 29.05.2019

Needfinding for a wind propelled autonomous surface vehicle

Thesis submitted for examination for the degree of Master of Science in Technology

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Abstract of master's thesis

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Abstract
Autonomous surface vehicles (ASVs) are a type of unmanned vehicles that operate on the surface of the water and can be utilized for assorted tasks by equipping them with different technologies. Various energy sources can be used for the motion of vehicle as well. Wind propulsion is one of the available methods of harvesting energy for movement from the environment, which has potential to increase the persistence of the vehicle in addition to other advantages. Other unmanned technologies for the marine environment exist and the topic of what wind propelled ASVs might be best suited for was explored. ASVs have potential to improve oceanographic data gathering for marine research with vertical profiling capability in shallow oceans, where other technologies are inefficient or lacking. With station keeping abilities ASVs have potential to compete with bottom moored buoys with cost efficiency. Autonomous surface vehicles can also utilize wireless communication technologies in order to provide real time data or interact with other equipment. ASVs could be used for passive acoustic monitoring research for detecting underwater vocalizations for the presence of animals in a given area with reduced costs. They could also be used to deploy and retrieve marine equipment and cut costs compared to current methods. However, current legislation limits the use of ASVs.

Keywords Autonomous surface vehicle, ASV, Unmanned surface vehicle, USV, Marine robot, Wind propulsion

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Tiivistelmä

Miehittämättömät pinta-alukset (ASV) ovat veden päällä kulkevia robottiveneitä, joita voidaan käyttää moniin tarkoituksiin varustamalla ne eri teknologioilla. Liikkumiseen voidaan käyttää erilaisia energianlähteitä ja energiaa voidaan kerätä myös ympäristöstä. Yksi tapa on tuulen avulla purjehtiminen, jota käyttämällä voidaan pidentää ASVn toiminta-aikaa. Purjehtiminen tarjoaa myös muita etuja. Meriympäristössä hyödynnetään myös muita miehittämättömiä teknologioita ja tuulivoimalla kulkevien miehittämättömien pinta-alusten etuja näihin verrattuna selvitettiin. ASVilla on potentiaalia parantaa merentutkimuksellisen datan keruuta mittaamalla vertikaaliprofiileilla matalissa merissä, joissa muut miehittämättömät teknologiat toimivat energiatehottomasti tai puutteellisesti. Positiotaan pitävät ASVt saattavat myös pystyä kilpailemaan pohja-ankkuroitujen poijujen kanssa kustannustehokkaasti. Miehittämättömät pinta-alukset voivat hyödyntää erilaisia langattomia tiedonsiirtoteknologioita tuottamaan reaaliaikaista dataa tai vuorovaikuttamaan muiden laitteiden kanssa. Miehittämättömät pinta-alukset saattavat myös soveltua akustiseen tutkimuskäyttöön tutkimukseen merieläinten ääntelyiden havainnointiin kustannustehokkaasti. Tämän lisäksi ASVt voisivat myös laukaista ja noutaa muuta laitteistoa meriympäristössä. Nykyinen lainsäädäntö kuitenkin rajoittaa miehittämättömien pinta-alusten käyttöä.

Avainsanat Miehittämätön pinta-alus, Autonominen pinta-alus

Foreword

As an avid fan of the marine environment I am really glad that I got to work for the ÅSR project. In the beginning of my thesis work I spent one month in the Åland Isles where the project is located and really enjoyed my time there. I want to thank the project manager Anna Friebe for providing the opportunity to write a thesis for a concrete project and for her support along the way. I also want to thank my supervisor Kalevi Ekman for his role in facilitating teaching for product development at Aalto Design factory which I thoroughly enjoyed during my studies.

In Helsinki 29.5.2019

-Niko Kyyrönen

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Glossary

ADCP	Acoustic Dopler Current Profiler
ASV / USV	Autonomous / Unmanned Surface Vehicle / Vessel
AUV/ UUV	Autonomous / Unmanned Underwater Vehicle
ASPire	A sailing prototype in the ÅSR-project Autonomous Sailing Platform
Argo float	A type of marine robot see benchmarking
Biofouling	The accumulation of microorganisms, algae or other biological aspects on wet surface over longer periods of time
COLREG	Internal regulations for preventing collisions at sea
CTD	Conductivity Temperature Depth
GPS	Global Positioning System
Glider	A type if marine robot see benchmarking
Harbor porpoise	A type of marine mammal
Iridium	Referring to the Iridium Communications Company providing satellite communications
MASS	Maritime Autonomous Surface Ship
PAM	Passive Acoustic Monitoring
Wingsail	An aerodynamic structure that can be used for propulsion
WPASV	Wind Propelled Autonomous Surface Vehicle
ÅSR	Åland Sailing Robots project

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1 Introduction

Autonomous surface vehicles (ASVs) are a type of unmanned vehicles that operate on the surface of water. In addition to ongoing development of large autonomous ships for global shipping applications, smaller vessels have been proposed and developed for use across different industrial, research and military applications. Multiple designs for ASVs exist in various stages of development in commercial ventures and research projects in universities and other nonprofit organizations. As with other marine vessels, different approaches exist for propulsion methods and the use of wind power has potential as an environmentally friendly alternative for fossil fuels. In addition to reducing pollution, the use of wind power has other strengths as well. By harvesting energy from the environment, persistence of an ASV can be increased considerably and the lack of noise from combustion engines can be utilized for uses in the marine environment with less disturbances to the marine species.

Åland Sailing Robots (ÅSR) functioning under Åland University of Applied Sciences is a project, where both theoretical methods and physical platforms for robot sailing have been under development and testing. The main focus of the project has been on solving numerous technical challenges required for autonomous sailing with a small sailing robot. Consequently, the exploration of practical applications and opportunities has been sparse. This thesis seeks supplement the project's research by identifying opportunities and developing application concepts for the use of wind propelled autonomous surface vehicles. A research question for the thesis is: *What needs can be met by utilizing wind propelled autonomous surface vessels in a way that they could outperform other alternative technologies?* The goals of the thesis are to identify and investigate applications where wind propelled autonomous surface vehicles could play a role. Further, the prevalent methods for said applications have to be researched as well, as potential for commercial viability of the product or service concepts is also coveted and therefore existing methods have to improved on both in terms of cost and performance.

The structure of the thesis is as follows. First, after the introduction a short description of methods for early product development is covered. Next, existing ASVs designs and other unmanned marine platforms are examined and other possible applications for research and industry uses are presented. Different ideation methods are then applied for innovating ideas for the use of ASVs in different applications and the use of wind propulsion is examined. Interviews that were conducted with representatives from various fields are presented and a general design direction for marine research is reasoned. An ideation workshop that was used to guide the remaining research is then covered. Further interviews for marine research uses are then presented and different concepts for wind propelled autonomous surface vehicles for specific applications are then reasoned. Finally, the methods that were utilized for the work are discussed.

1.1 *Background*

As with many other novel technologies, unmanned surface vehicles have their beginnings in military applications, where rudimentary ASVs were first used for mine clearing, collecting radioactive water samples following nuclear blasts and target practice among other uses [1]. Different military applications were the main use for ASVs until 1990s, during which other uses also emerged. This was largely due to technological developments and more autonomy could be implemented into the vessels with improved communications [2]. Over time various hull and propulsion designs have been developed for numerous uses. In more recent years much more capable platforms that utilize modern communications technologies and advanced levels of autonomy have been under development at several commercial and non-profit organizations as further detailed later on in the thesis.

The Åland Sailing Robots project began in 2013 with goals of crossing the Atlantic Ocean and several designs have been under testing and development. More recently the focus was on developing a marine research platform. The ASPire (Autonomous Sailing Robot) prototype seen in figure 1 is based on a 2.4mR class sailboat and is equipped with a free rotating wingsail. The prototype is equipped a power system, sensors for navigation and a thermal imaging camera for collision avoidance purposes.

Figure 1: The ASPire prototype in fall 2018

2 Design methodology

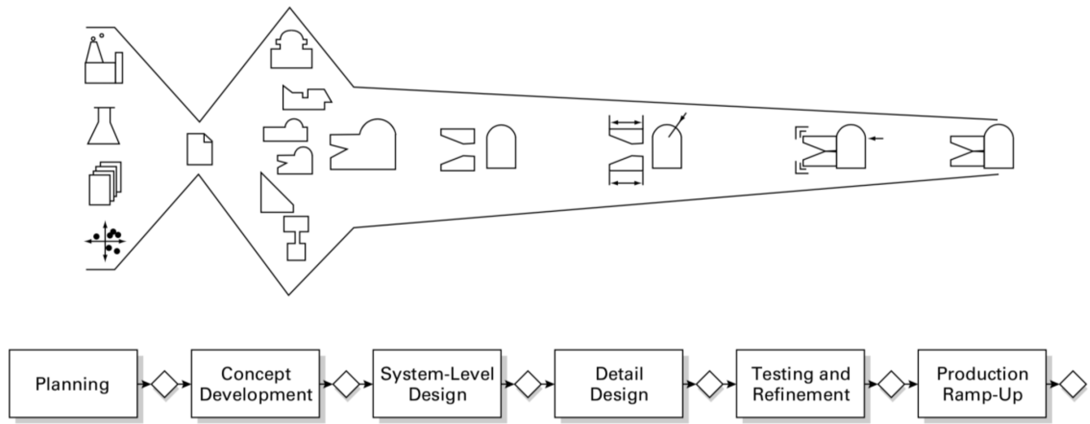


Figure 2: A generic product development process [3]

Figure 2 shows a generic product development process divided into different sections. From this processes' standpoint the activities in this thesis are concentrated on the early phases of planning and concept development. The early phases of product development processes begin with opportunity identification, which in a corporate context would be guided by internal forces, such as corporate strategy and market objectives. From the planning phase a *mission statement* would be generated that would define goals for the coming process. In this thesis, since the work is done for a research project without current intentions into moving beyond concept development, the inputs are in the form of the goals of the ÅSR project to develop commercially viable concepts for small wind propelled autonomous surface vehicles, hence the research question of: *What needs can be met by utilizing wind propelled autonomous surface vessels in a way that they could outperform other alternative technologies?* The research question has been augmented with the early opportunity identification that wind propulsion could be a viable means of increasing an ASV platforms' persistence in an environmentally friendly way and low noise from its use could be utilized in different ways. However, these assumptions will have to be further analyzed in the coming process. The research question then acts as the mission statement for the rest of the product development activities. The next phase *concept development* includes several front-end activities. The needs of the desired customers will need to be identified, then target specification for meeting the needs are established. Concepts are then generated to meet said needs and the most promising ones are taken further for testing. Based on the testing and iterations the most suitable ones are selected to be taken on to the system level design. For this thesis the emphasis will be on identifying customers for the wind propelled ASVs and target specifications will be derived from other existing technologies and methods that could be or are used instead of WPASVs. Concepts will then be generated for meeting the needs. In this thesis the concept testing is limited to gathering feedback for ideas on use cases from possible customers. [3]

The above-explained method is highly generic and better suited for identifying and developing for previously unfilled needs. A better way of thinking might be to consider the wind propelled autonomous surface vehicles as a technology-push, where efforts are made in finding a need or a novel application or product where the technology in question would perform well, preferably better than the alternatives. In a way trying to find a place for a piece (the technology) in a puzzle. A possible pitfall in this approach is trying to jam a technology into an environment where it has no place as other methods are better suited. Lastly, the WPASVs are also a platform product for others to build on. Meaning that the WPASV is a technology platform that can be utilized for other uses, much like computers or cars. An important consideration is that all of the design issues in the platform will need to be developed to a high enough degree of performance. If your computer keeps crashing or your car won't start, the usability of them is not very high.

With these general considerations, the design development began with benchmarking, which went on during the thesis work.

3 Design development

This section of the thesis consists of benchmarking various existing platforms and literature. Some design goals are then set and the design space is explored. Interviews are then conducted across multiple fields in order to define a further design direction.

3.1 *Benchmarking*

Utilizing autonomous vehicles for assorted tasks, is a concept which is currently being explored and implemented in various stages of development by companies and non-commercial research projects at universities and other organizations. Therefore, it is worth to explore the designs of existing platforms. In this section several commercial autonomous platforms are presented in terms of type, performance characteristics, and proposed suitable applications. The platforms that are presented have been limited to commercial platforms, since they have been developed to a stage where commercial ventures are possible, implying that all areas of development have been met at least to the level of a minimum viable product. Additionally, up-to-date information and real-life case studies are also available. In addition to autonomous surface vehicles, profiling floats underwater gliders and moored installations are also briefly discussed, as they represent other autonomous means of data gathering in the oceans.

3.1.1 Wind Propelled ASVs

SailBuoy

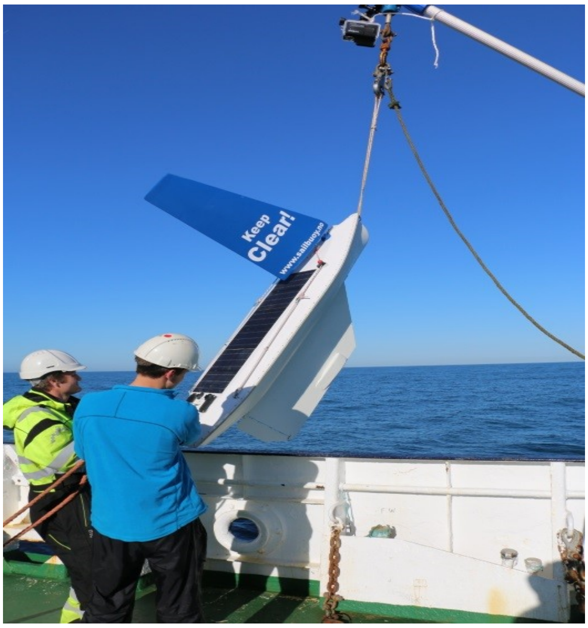


Figure 3: A SailBuoy being hoisted with a crane [4]

Organization: Offshore Sensing AS, Norway	Power source: Wind & Solar
Propulsion: Wingsail	Size: L 2.0m, Weight: 60kg

Table 1: SailBuoy characteristics [5]

The SailBuoy is wind propelled USV that recently completed the first transatlantic crossing of an unmanned surface vehicle. The voyage took 80 days and took place in the summer/autumn of 2018. The SailBuoy provides its electronics with power from solar panels mounted across the deck of the vessel. The platform utilizes the commercial iridium satellite constellation for two-way communication and control. The SailBuoy is able to navigate in winds up to 20 m/s and survive all weather conditions. Maximum duration for missions is 12 months with an average speed of 1-2 knots. The platform has a payload capacity of approximately 15 kg, with a volume of 60 liters. A website is provided with the ability to send waypoints and recover data from the vessel. A variety of sensors can be mounted to the vessel for scientific and industrial applications. [5]

The SailBuoy's wingsail has a comparatively small surface area. In contrast, it utilizes a large keel in relation to the vessels size than most other platforms. Both elements are visible in Figure 3. These design choices likely have to do with the vessel's ability to withstand harsh conditions and avoid entanglement or damage to or from other objects at sea, abilities that are promoted on the company's website.

Among other campaigns, in 2013 a SailBuoy was deployed in the Gulf of Mexico for 62 days for the purposes of: *"(1) monitoring of the physical properties of the GoM (SST, SSS and O2); (2) demonstrating the utility of using a remotely controlled vehicle for reliable data collection; and (3) providing a system for validation of relevant remote sensing data and model simulations."* [6]. The measurements of the ocean parameters from the onboard sensors were found to be of high quality and drifting of the sensor readings or biofouling did not seem to cause problems over the deployment period. The measurements were compared to remote sensing data and hydrodynamic model outputs for comparison and validation, with promising results for the usefulness of such a platform. [6]. Another paper [7] details the use of a SailBuoy for wave measurements in the North Sea. The SailBuoy was equipped with a GPS-based Datawell MOSE G1000 sensor, which relies on Global positioning data to calculate wave characteristics. During this study, a SailBuoy utilized its sailing ability to maintain a position at two waypoints, where measurements were collected. The vessel held position within ±2 km for about a week at both waypoints during rough weather conditions. The data was then compared to results from a bottom mounted buoy. The datasets from the SailBuoy and the comparison buoy had a very good agreement, with the exception of small waves, where the motion of the vessel likely have influenced the results. It was concluded that a SailBuoy was a suitable platform for producing both real time and post processed data for wave measurements.

Saildrone

Figure 4: A Saildrone in the Pacific ocean [8]

Organization: Saildrone Inc, USA	Power source: Wind, Solar
Propulsion: Wingsail	Size: Length 7 m, Height 5 m, Weight: ~431 kg

Table 2: Saildrone characteristics

Saildrone a California-based company that offers 'data-as-a-mission' services with their fleet of Saildrone ASVs. The Saildrones are on the larger side of the existing unmanned sailing platforms at 7 meters long and weighing in at around half a ton. Every Saildrone is equipped with close to 20 different sensors and cameras at different locations under and above the water level [9]. The sensors can provide measurements for atmospheric, physical and oceanographic measurements. The Saildrones are capable of missions up to 12 months and are equipped with iridium satellite connectivity for real time data capabilities through a web portal. Transit speeds of the saildrone are approximately 3 knots with a maximum speed of approximately 8 knots. The payload capacity of the Saildrones is 250 lbs (113,4 kg) and steady state power is stated at 30 watts.[9]

In 2015 two Saildrones were used in exploring the capability of utilizing USVs for long duration missions to gather oceanographic and atmospheric data in the Berring Sea and Norton Sound. The Saildrones were shipped in 40ft shipping containers. After assembly, sensor testing and validation, the Saildrones were deployed to the water. Over the 97 days at sea, the Saildrones averaged 600 samples per minute, which were stored on board in raw data and filtered data was sent via satellite to shore every 6 hours.
The suite of sensors included 11 sensors for oceanographic and atmospheric measurements, as well as 4 cameras for situational awareness. Both of Saildrones travelled over 4100 nm, with speeds averaging 1.9 knots. In addition to the data sets, the ability to re-task the drones in real time based on the observations was also demonstrated. [10]

In 2016 two Saildrones were again dispatched to the Bering Sea, this time to listen to marine mammals with passive acoustics and to quantify the spatial distribution of fish populations with active acoustics [11].

In the first half of 2018, two Saildrones were dispatched to a region called ‘White Shark Café’, a region in the Pacific Ocean roughly halfway between California and Hawaii. The Saildrones were used as part of a larger collaboration between a multidisciplinary team with aims to better understand the region and migratory habits of great white sharks. During the campaing, Saildrones were utilized as scouts that were deployed to the region in advance of arrival of manned crews and during their stay. The Saildrones utilized echo sounders and acoustic receivers to detect specific layers within the water column, as well as listening to sharks, previously tagged with acoustic tags.[12]

Another measuring campaign relating to fish stock assessment was conducted later in the summer and fall of 2018. Five Saildrones were used and they utilized echo sounder sensors to collect data on the fish stock of three types of fish. The Saildrones were used in conjunction with traditional ship-based methods, both by duplicating the path of the manned ship and conducting measurements closer to shore, where larger manned ships have difficulty navigating. [13]

Submaran

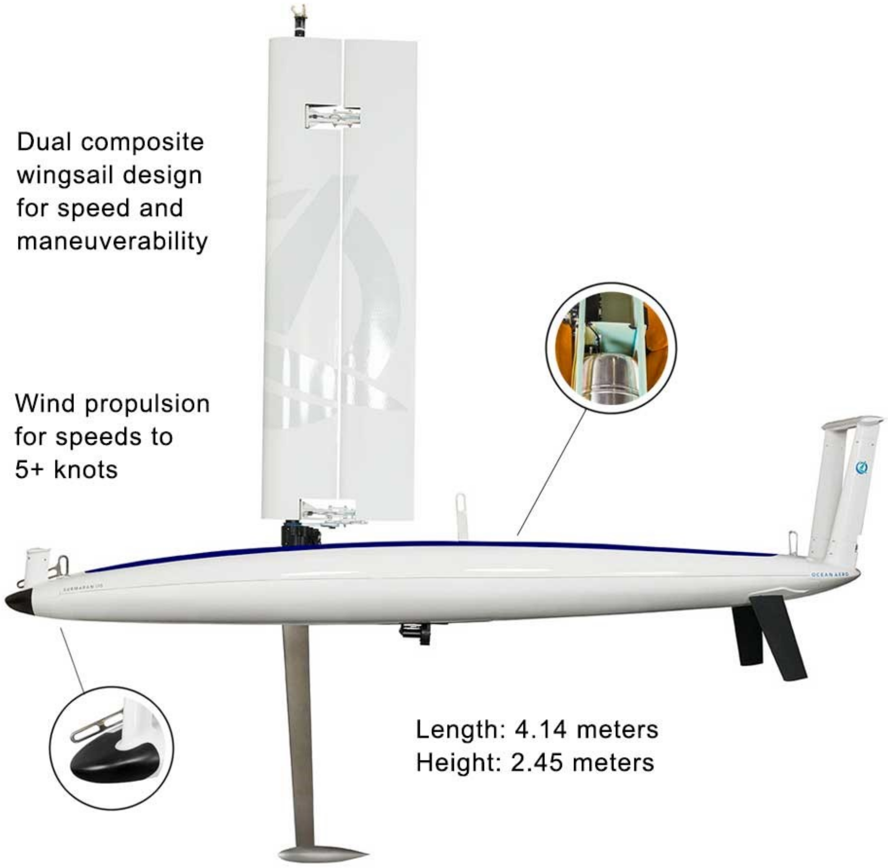


Figure 5: The Submaran [14]

Organization: Ocean Areo, USA	Power source: Wind, Solar
Propulsion: Wingsail, (propeller)	Size: Length 4.14m x Height 2.45m, Weight: 127kg

Table 3: Submaran characteristics [15]

The Ocean Aero Submaran is a platform that has combined surface and subsurface capabilities in a single craft. This is achieved by utilizing a two-part wingsail while operating on the surface that can be folded away after which the craft can submerge by controlling its ballast tanks. An electric motor provides thrust while operating underwater and steering is controlled with two rudders in a non-parallel configuration for both surface and subsurface operation. The craft is equipped with a 23kg payload area and can provide 50 watts of continuous power with 300 watt peak power from solar charged lithium batteries. Top speed of the platform is 5.5 knots [15]. [14]

Ocean Aero suggests that the Submaran is a suitable platform for various uses across different sectors. These include environmental data gathering and sampling, gateway communications, ocean floor mapping and asset surveillance. A two-person team can launch and recover the vessel and a distinctive ability is to evade bad weather or detection by mean of submerging. [14]

3.1.2 Other propulsion methods

In addition to wind propelled ASVs, several other platforms that utilize other means for moving across the water also exist in various stages of development. Here three more benchmarks of established vessels, with two different propulsion methods are presented.

AutoNaut

Figure 6: AutoNaut 3.5 Comms Hub launched in 2019 [16]

Organization: AutoNaut, UK	Power source: Solar, Wave energy
Propulsion: Wave energy, additional propulsion	Three sizes: Lengths: 3.5, 5, 7m Beams: 0.67, 0.8, 0.9m Displacements: 150, 230, 500kg

Table 4: AutoNaut characteristics [17]

Wind is not the only method for utilizing environmental forces for propulsion of surface vehicles. Another method is to harvest wave energy and the AutoNaut does exactly that. This platform comes in three different sizes and utilizes wave foil technology with optional electric propulsion configurations. The wave foil technology converts the movement of the vessel that is caused by waves to thrust. This is achieved with fore and aft keel mounted foils, seen in Figure 6, that articulate in relation to the pitch of the hull and convert the movement into thrust. The vessel comes in three different sizes and with increasing size, both payload and speed are increased. The smallest 3.5 meter option has a speed of 1-3 knots with wave energy and the largest 7 meter option has speeds of 4-5 knots. The largest vessel has a payload of 150 kg with a volume of 1580 liters. [17]

As with other manufacturers, AutoNaut proposes several marine related applications for their platform from marine surveying to use as a communications gateway and also provide sensor options for their platform for different uses in their website. Additionally, two case studies are provided for 'acoustic Doppler current profiling' and 'quantifying and monitoring fish stocks' are available on the AutoNaut website. Both case studies provide brief descriptions of the organizations, equipment, methods and timeframes of the studies but the performance of the vessels in the applications is detailed only very generally. [18]

In 2019 AutoNaut launched its new Comms Hub vessel, specifically oriented for use as a surface communications gateway. This product is proposed for use for data harvesting, likely from other installations without direct communications (see moorings-section in this thesis) and precision positioning, likely referring to guidance of gliders other unmanned underwater vehicles. [16]

Wave Glider

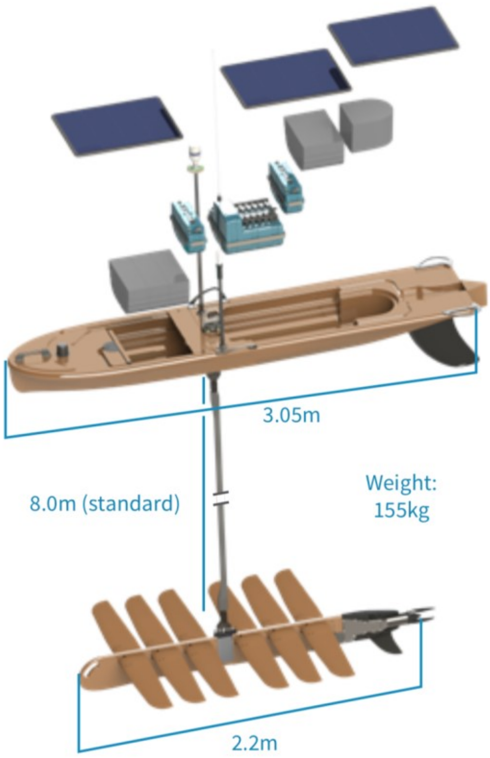


Figure 7: The Wave Glider [19]

Organization: Liquid Robotics, Inc, USA	Power source: Solar, Wave energy
Propulsion: Wave energy, (propeller)	Size: Length 3.05 m, Width 0.81 m, Weight 155kg

Table 5: Wave Glider characteristics [19]

The Wave Glider is another platform that utilizes wave energy for propulsion. The platform consists of a surface float and an umbilical tethered sub seen in Figure 7 The unique two-part architecture converts wave motion into propulsion. In addition to wave energy an optional electric propeller can be fitted for increased dimensional control. Additional power is gathered with solar panels that cover most of the surface floats' top layer. Together these technologies provide a high endurance for missions up to a year at sea. With wave energy the Wave Glider can reach speeds of 3 knots with an average of 1.8 knots. A notable aspect of the design is its high capacity for towing loads up to 500 kg. For equipment onboard the float, a maximum payload of 45 kg in 93 liters is provided.[20]

L3 ASV - C-Enduro

Figure 8 L3 ASV C-enduro surface vehicle [21]

Organization: L3 ASV, UK, USA	Power source: Diesel, Solar, Wind
Propulsion: 2 x DC brushless motors	Size: Length 4.75 m, Beam 2.22 m, Weight 910 kg

Table 6: C-enduro characteristics [21]

In addition to utilizing energy that is harvested from the environment, there are of-course more traditional approaches to propulsion with propellers and internal combustion engines. One such design is presented here. L3 ASV is a manufacturer with a large lineup of autonomous surface vehicles of various shapes and sizes. The company designs, builds and operates ASVs for various military, scientific and commercial activities. The C-enduro is one of their platforms intended for long endurance missions and build to operate in all marine environments. The vessel utilizes a twin hull self-righting design. The vessel is configured with solar panels and a wind turbine to produce power and increase the deployment period of the vessel. Propulsion is achieved with propellers on DC motors that are powered with a diesel generator. The speed of the platform is up to 6.5 knots. Endurance is stated at 30+ days depending on the configuration and environmental factors. In addition to above surface sensors, bellow surface sensors can be mounted bellow deck, on the keel or a winch. [21]

3.1.3 Other platforms for marine environmental measurements and sampling

In addition to the selected surface vehicles in the previous chapter, Argo floats, gliders and moorings are briefly presented here, as they will be discussed further on in the thesis.

Argo floats

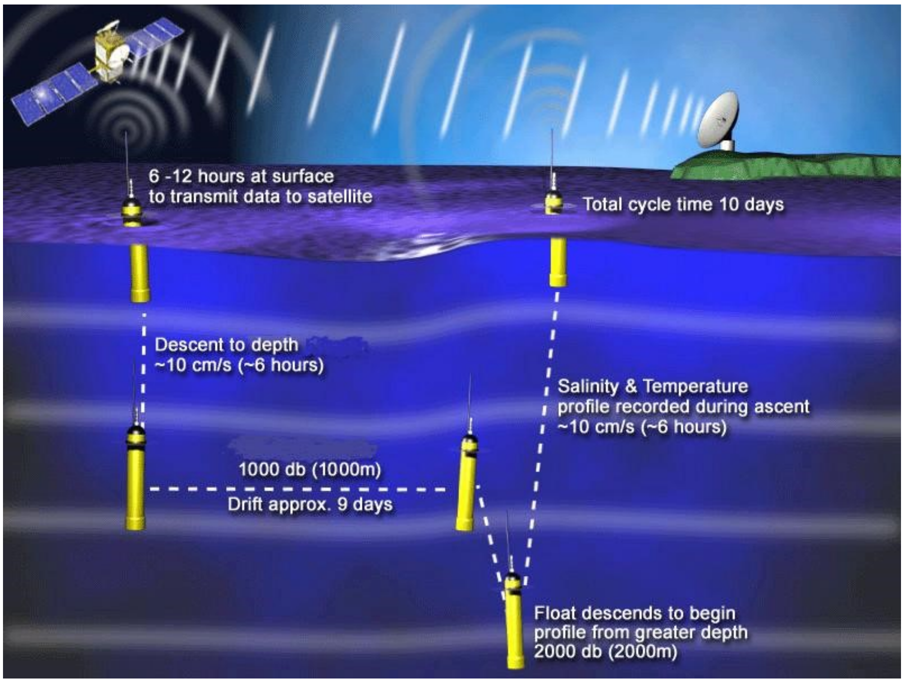


Figure 9: Argo floats drift underwater with ocean currents [22]

“The hot air balloons of the oceans”. Argo floats are a type of oceanographic instrument used to collect temperature and salinity profiles from the upper 2000m of the oceans. The floats utilize changes in their buoyancy to sink and establish neutral buoyancy to the surrounding environment after which they drift with ocean currents. An internal pump is used to pump fluid into an external reservoir to change the buoyancy of the floats. Typically the floats surface at intervals of 10 days and relay their data to satellites before sinking again to repeat the cycle. Argo floats are a well-established global standard with deployments beginning in 2000 and continuing today with around 800 deployments annually. [22]

Gliders

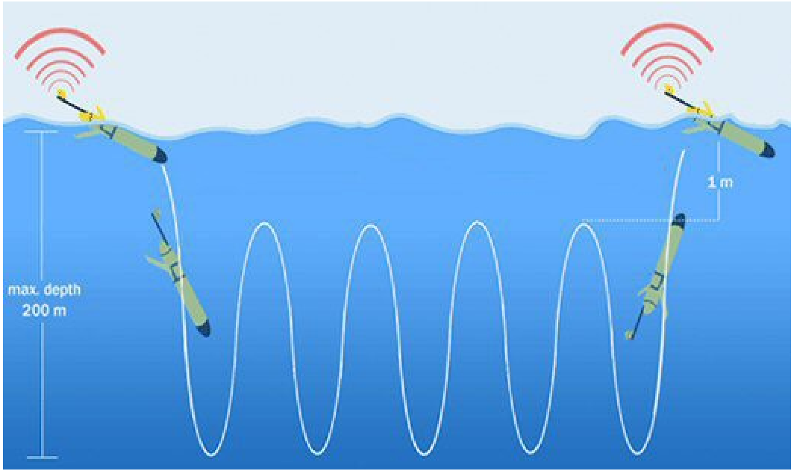
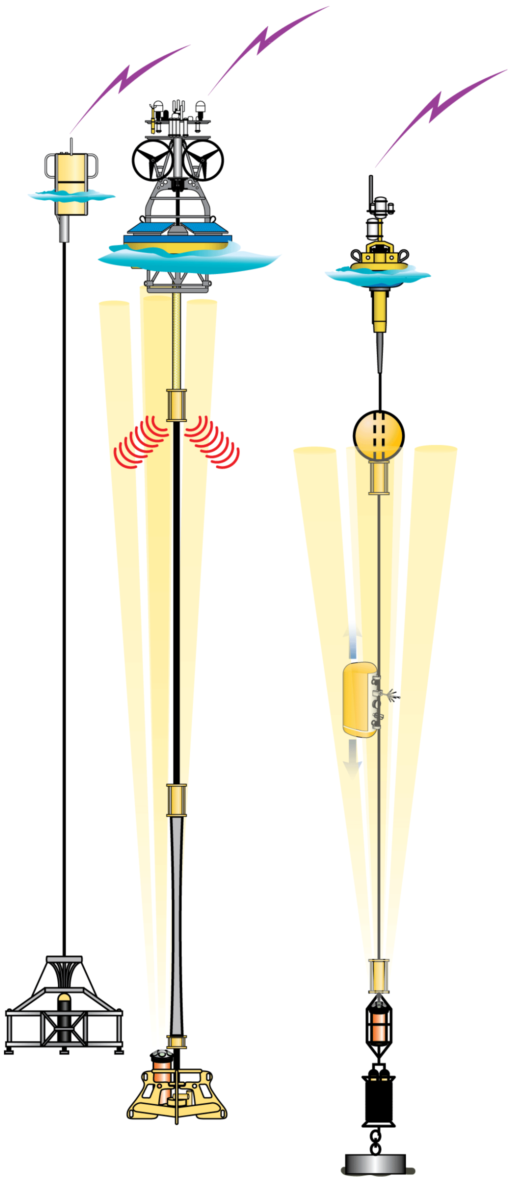


Figure 10: Gliders move underwater in a sea-saw pattern [23]

Similarly to Argo floats, gliders are a type of robotic underwater vehicles that move underwater by changing their buoyancy. They use an internal pump to pump oil to an external bladder and the resulting vacuum inside the main hull to suck the oil back inside the vehicle, causing the glider to either sink or ascend. This combined with movement of internal weights and small wings enable the gliders to translate the vertical movement into guided forward motion, as in Figure 10 Gliders can be equipped with sensors for various tasks and utilize two-way satellite communications that can be used while the glider is surfaced. While the gliders are surfaced, its progress can be monitored and changes to the mission can also be altered. [23]

Moorings



Moorings are a method to deploy sensors fixed or variable depths from the sea floor. They consist of an anchor or a weight on the ocean floor and a line to which one or more buoyant floats are attached. Moorings can have surface expressions, often in the form of buoys, which can be equipped with communications, additional sensors or power generating abilities. Moorings that lack a surface expression above water are called flanking moorings and can use flotation devices to fix sensors at different depths. As these mooring lack surface expressions, they cannot use satellite communications and data can be communicated via an acoustic link (a type of underwater modem), cables to shore or offline storage that is later retrieved with the equipment. Moorings can utilize sensors or other equipment at fixed depths or attached to profilers that move up and down the mooring line. [24]

Figure 11: Different mooring setups [24]

3.2 *Further literature on other proposed use cases for ASVs*

In addition to the benchmark platforms in the previous chapter, a further literature review was conducted in search of other proposed and realized applications for unmanned surface vehicles and is the topic this section. Emphasis was put on discovering documented us cases across a broad category of industries.

Military applications have high incentives for the use of unmanned platforms. These include mine counter measure, anti-submarine warfare, surveillance and reconnaissance [25].

Potential safety and security uses for micro USVs is discussed in [26]. A small USV EMILY (Emergency Integrated Lifesaving Lanyard), intended for use as a small first response unit for aiding swimmers in distress is presented. Another version, the Hurricane EMILY platform for measuring physical parameters is also shown. The use of micro USVs as first responders to illegal smugglers is presented as an option to reduce concerns of manned vessels running into potentially dangerous situations. Further smuggling related uses include searching of waterways, beaches and harbors for anomalies.

Network centric operations, where ASVs are used a communications hub to provide communications or analytical capability for other unmanned or deployed technologies [27].

The use of USVs for shoreline mapping with machine vision by utilizing an omnidirectional camera has been tested [28]. Shoreline mapping with USVs could be used to improve maps and study annual changes.

Unmanned inspections of infrastructure are another close to shore application [29]. Bridges and other pieces of infrastructure, that are in contact with seawater are especially prone to corrosion and require periodic inspections both above an under water. Environmental factors, such as strong currents are potential hazards for divers that are routinely used to conduct inspections. Additional hazards for inspectors can be created by damages caused by hurricanes or other weather anomalies.

Environmental disaster responses are another use case for ASVs. The 2010 *Deepwater Horizon* accident was a reminder of the devastation that can be caused by oil spills and affirmed the need for better understanding for oil spill drifting behavior. Early detection of oil spills and real time tracking are important factors in organizing an effective response and mitigating the impacts and methods for utilizing ASVs for tracking oil spills have been developed [30].

The use of a fleet of ASVs for passive acoustics monitoring of fisheries has been proposed as an alternative for replacing manned missions. With a fleet of ASVs current methods could be improved in significantly and silent platforms such as the wave gliders have been proposed as particularly suitable. [31]

L3 ASV's use cases

Another notable source of use cases are manufacturers case studies, where the manufacturers are keen to prove their technologies. One manufacturer is singled out here and their case studies are quickly covered. L3 ASV is currently one of the more notable companies specializing in the development of ASVs. Their lineup is ASVs has been used for different applications and many of the case studies concentrate on industrial applications such as [32]:

Cable route surveying – A seabed survey for a marine cable routing purpose with the use of a multibeam sonar, sub-bottom profiler and a winch deployed side scanner sonar. Cable survey lines were covered for a total of 1220 km.
Touchdown monitoring – Utilizing an ASV as a support element for laying pipeline in the Mediterranean, by providing subsea communications for improved location accuracy.
Coastal survey - Construction support for a breakwater structure, by utilizing a multibeam sonar for seabed scanning.
Down well data interrogation – Data collection from gas wells with an acoustic modem.
Passive acoustic monitoring - Monitoring for detection, classification and localizing marine mamals in the gulf of mexico.
Hyrdographic surveys – Off the coast of UK.
AUV tracking – Telemetry tracking for an autonomous underwater vehicle to improve data collection by providing better positioning and guidance data.
AUV launch and recovery – Launch and recovery of micro AUVs

Force multipliers and combined systems

In the previous oceanography international 2018 conference in London several presentations were held with connections to the use of ASVs. The information related to these presentations the use of combined systems with an unmanned surface vehicle (USV) and an autonomous underwater vehicle (AUV) are presented with the general idea of combining the use of both platform types. The concepts appear to utilize an USV to transport, deploy and recover an AUV, while providing communications and guidance to the AUVs while they are deployed. From reviewing other presentations in the 'Unmanned Vehicles & Vessels Technical Track', one of the general trends appears to be the visioning and development of interconnected systems with swarms of ASVs, USV, areal drones and docking stations. Especially the use of AUVs swarms for ocean floor mapping is a prevalent topic. In addition the development of tools for supervision and guidance of unmanned vehicles is another frequent topic.[33]

Outside of the oceanographic, industry and military applications, an interesting and a particularly bold concept is the use of WPASVs to transport renewable energy between major cities for remote islands. Everblue technologies is a Japan-based starup that envisions a solution for transporting renewable energy by first using the energy to produce hydrogen as a ways to store said energy. Next a fleet of autonomous sailing boats Figure 12 is used to transport the hydrogen via a distribution network in the ocean to where the energy is needed. [34]

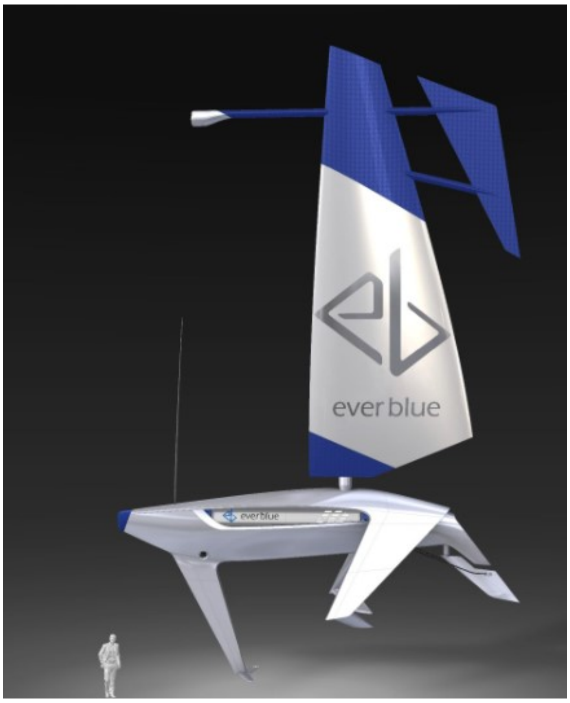


Figure 12: A concept image from Everblue technologies of a hydrogen transportation sailboat [34]

3.3 *Learnings from benchmarking*

From benchmarking it is evident that the use of ASVs for applications across various sectors has been ongoing for some time and several designs exist in various configurations. Different technologies have been developed for propulsion and particularly, other commercial platforms that utilize wind as a propulsion method exist as well. Accomplished and proposed applications vary across different fields and a common practice is to utilize designs that allow for the configuration of additional equipment to better fit the needs for different applications. Furthermore, the ASVs have been used for different roles, sometimes as independent data gathering platform and other times as a part of a larger network of machines or manned vessels. Some manufactures provide a service model for access to their platform and others are selling the platform as a product. Indeed, the designs and uses for ASVs vary across multiple dimensions.

3.4 *Opportunity Identification*

In this section, innovation methods are used to identify opportunities for the use of wind propelled autonomous surface vehicles.

3.4.1 Innovation charter

From benchmarking existing ASVs platforms, it was found that their use cases vary across multiple dimensions. Technological developments in sensing technologies and their suitability for implementation into autonomous platforms is also a grey area. Further, the legislation for autonomous marine vessels is evolving and being developed internationally and within local legislation, as explained in the legal status of ASVs section of this document. Uncertainty still surrounds future legislation, required classifications and no clear timeframe exists for the legislation.

For the work in this thesis, an innovation charter for guiding the design process is defined as:

"Sense and develop applications for wind propelled autonomous surface vehicles, which are attainable with current technological capability and are likely to conform to legislation of the coming decade."

For a more thorough charter, organizational and business-oriented aspects could be included, but due to the research project status of the ÅSR-project, these are left outside of the charter. In the charter, 'current technological capability' refers to existing technological ability, which is available and could in theory be utilized within reasonable speculation. Meaning that the technological aspects for the applications, such as onboard power- and communications requirements can be fulfilled with existing technological ability with expectations of reasonable performance.

3.4.2 Mapping out the design space

An autonomous surface vehicle can be considered an entity or a platform that is capable of observing and interacting with its environment, while traveling or holding a position on the surface of the water. It could be equipped to sense, emit, gather or process a multitude of things from feeding fish to generating hydrogen. In order to explore the possibilities for ASVs, a chart in the form of a concept map was generated, by connecting related senses and abilities that a surface going vehicle could be equipped with. The drawing is presented below in Figure 13.

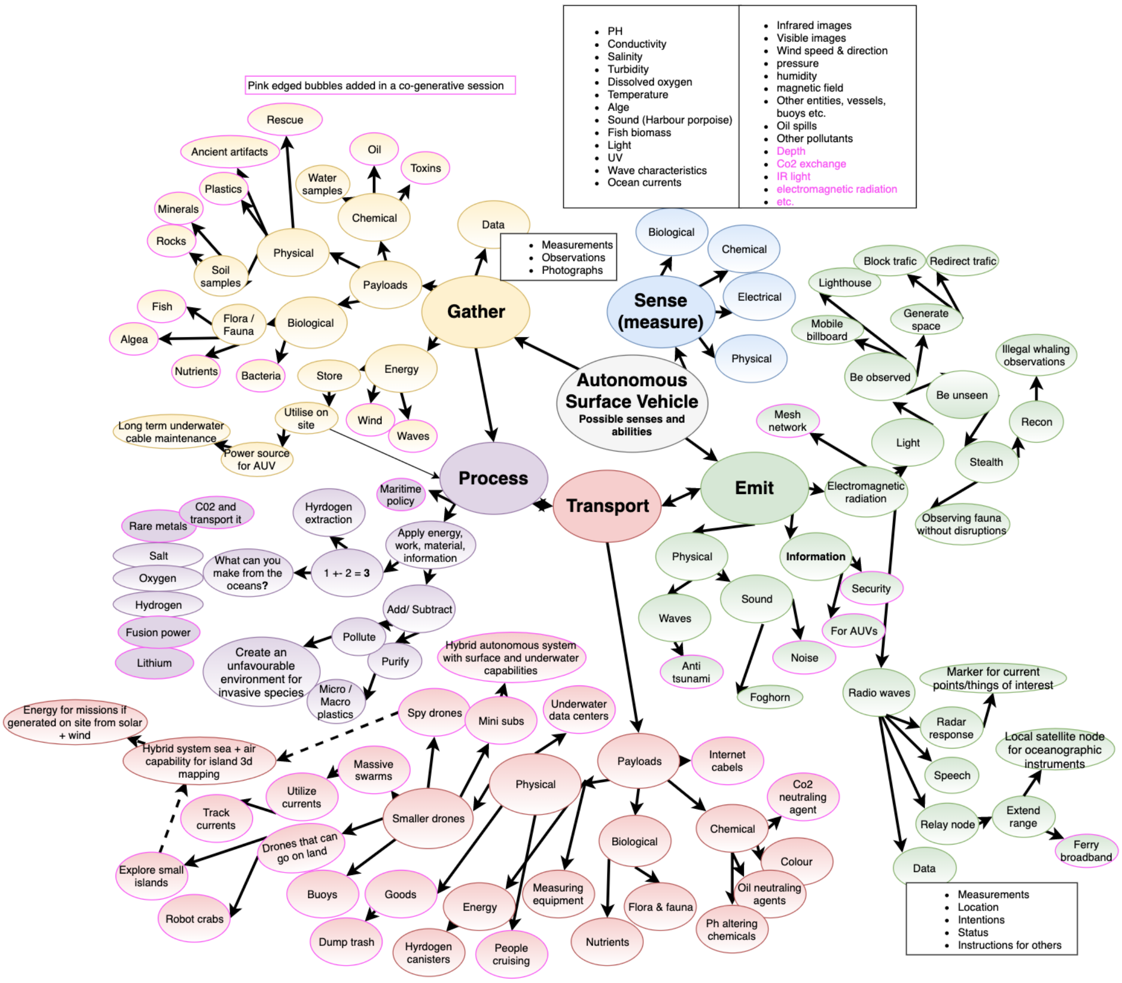


Figure 13: ASV senses and abilities

By grouping different aspects and considering the related sub-categories, eventually more or less specific opportunities emerge or at least become more easily discoverable at the end of these chains. One such example of a chain is: Emit - Electromagnetic radiation - Radio waves - Relay node - Range extender - Local satellite node for oceanographic instruments without designated long range communications. It was important to have enough links in the chain, so that the individual links could be further explored and expanded on.

3.4.3 Early exploration of the design space

During the early phases of opportunity identification, several interns who had been working on the ÅSR-project were at the end of their internship and leaving the project. In order to try to capture their knowledge and possible ideas, an ideation session was conducted. The session was conducted in two phases: The first phase involved the 'senses and abilities'-drawing, which was expanded on and more importantly utilized as a tool to facilitate an expanded mindset for the more specific goals in the second phase. 30 minutes were spent with a facilitator guiding the ideation, with a sub task of creating an open-minded mindset, by encouraging and supporting also the more outlandish ideas and additions. Some of which are found in the 'senses and abilities' drawing. The 1st phase was concluded with an individual tasks for the participants to each add 10 additions to the mindmap in 10 minutes as seen in Figure 14.

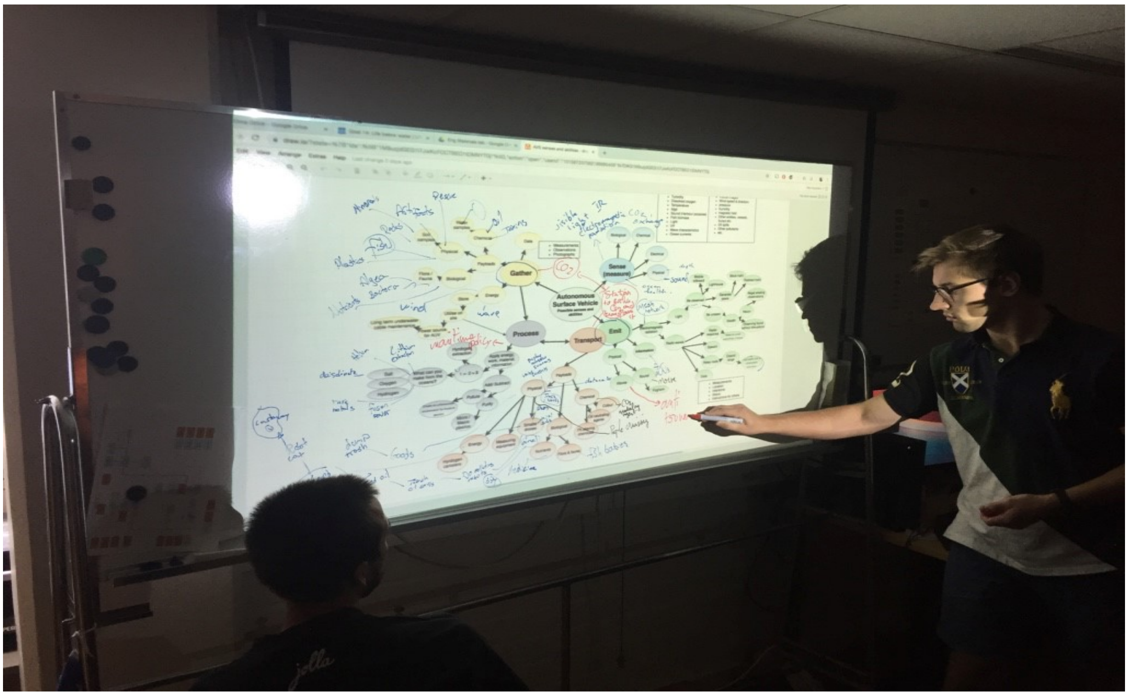


Figure 14: A projector and a whiteboard with markers were used for the first part of this design session

The second phase was a variation of the 6-3-5-ideation method, in which each participant generates a rough idea on paper, which is then handed to the next person, who expands on the idea with their input. Each idea sheet passes through each participant, giving them the opportunity to offer fresh perspective and new additions to the ideas, without the sometimes unbalanced group dynamics of more verbal design methods. The name 6-3-5 comes from 6 participants, 3 ideas and 5 rounds. In this exercise a 5-2-4-version was conducted with 5 participants, two ideas per person and 6 minutes per round, until the ideas were handed clockwise to the next person. For better tracking of the additions, each participant had a unique pen color as seen in Figure 15 and the 'senses and abilities'-mindmap from the 1st phase was visible for inspiration. The task for the exercise was to 'Ideate use cases for ASVs'.

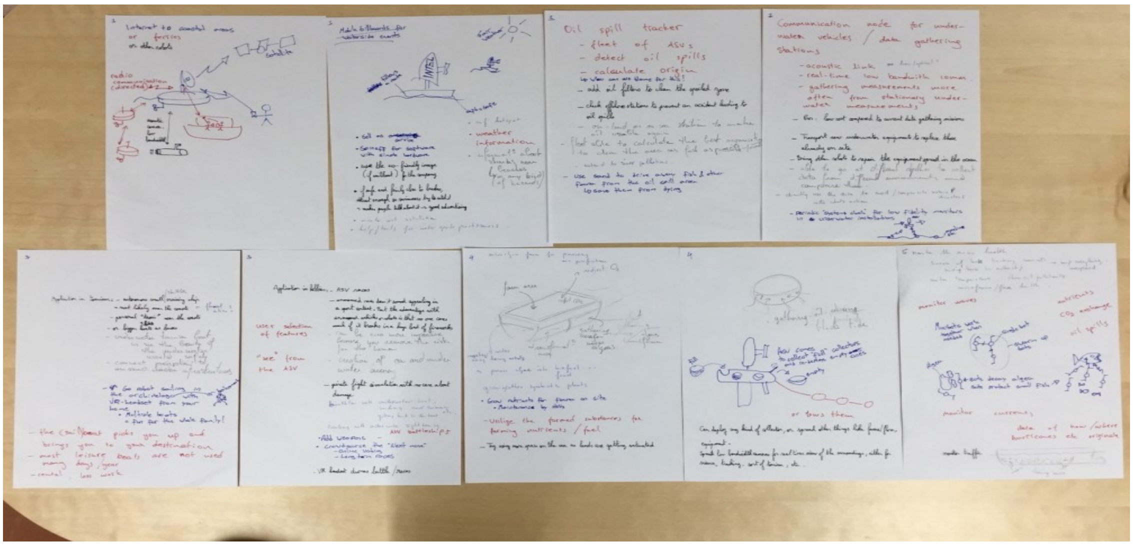


Figure 15: Idea sheets generated in the '5-2-4'-exercise. Illustrations, text and different colors for each participant were used.

After the exercise the idea sheets were reviewed by the facilitator and the most interesting and thought provoking aspects of the ideas were highlighted. The structure and task of this exercise were quite open-ended and the results reflected this. In many of the idea sheets, the initial idea was taken to other directions by the contributing participants, resulting in mixed direction with several add-ons. Table 7: Short summaries of the ideas generated in the 5-2-4-exercise summarizes the ideas for applications created in this exercise.

Idea	Business sector	Description
ASV races	Sport / Entertainment	Unmanned racing with ASVs equipped with thrill invoking aspects such as fireworks and weapons without risks for the operators. VR-headsets for situational awareness, possibilities above and sub-surface stages or long-term stages with online crowd-sourced strategies
Physical shuttle services OR Remote augmented reality cruising	Tourism / Entertainment	Utilizing ASVs for transporting people between places or in a cruise fashion. Also underwater to experience the sub-surface world. OR Utilizing a VR-headset to go remotely sailing with friends/family in selected locations from the comfort of your home. Also as a possible activity on cruise ships etc. via on location launched vessel. Enhancing the experience with augmented reality.
Mobile billboard for waterside events OR	Advertising / Local hazard detection	Utilizing a WPASV's sail as real estate for ads or other promotional material for waterside events by having the ASV cruise around at the event. This

Information on possible hazards		would be a low-cost 'spin off' for the navigation software with a novel and eye-catching application in an environmentally conscious way. OR Utilizing a patrolling ASV at beaches to warn about sharks or other possible hazards.
Providing internet for coastal areas, ferries or other robots	Data communications provider	Providing expanded communications for other surface equipment, people or underwater robots.
Communications node OR Maintenance for underwater vehicles and installations	Support for oceanographic instruments	Acoustic or optical link for data transfer for underwater installations or vehicles. Downloading offline measurements and utilize the ASV for periodic systems check for underwater installations without designated outgoing communications OR Using ASVs to transport 'maintenance robots' to marine installation and equipment, which would then perform maintenance or repairs on site.
Marine farming or processing plant	Processing and farming	Processing algae to biofuels of food while binding carbon dioxide and releasing oxygen.
Oil spill tracking and damage control	Environmental monitoring	Fleet of ASVs detects and calculates the origin of oil spills. Additionally, ASVs could use acoustic or other means to drive away fish, birds and other marine animals from the affected area to mitigate harm to them. Similar systems could also be used for other pollutants.
Environmental cleanup or monitoring with deployable equipment	Environmental cleanup and monitoring	Utilizing ASVs to deploy and gather various collectors or monitoring equipment. Collectors for oil, plastics etc. Deploying other things such as flora or fauna. Low bandwidth cameras or other transducers for a real time assessment of the surroundings.
Ocean health monitoring with robot swarms	Environmental cleanup and monitoring	Utilizing a swarm of bots for various tasks such as cleaning ship hulls, tracking nutrients, protecting small fish from predators. Swarm would periodically return to 'mother ship' for maintenance or re location etc.

Table 7: Short summaries of the ideas generated in the 5-2-4-exercise

Reflecting on the exercise

Reflecting on the ideas shows that they have a considerable amount of variety in several dimensions. First, multiple uses in different business sectors were ideated. This can be considered a reflection of the presence of different and varied activities in the maritime environment from shipping to leisure activities. Autonomous systems then offer several possibilities in advancing existing activities or enabling new ones. Second, it is worth noting that between the ideas, the role in which ASVs are used varies between supporting elements of a larger system and more exclusive roles. Third, the use of hybrid systems as a means extend the capability of ASVs from the surface also to sub-surface and airborne capabilities became evident. Similarly, utilizing swarm intelligence to create a system with a larger impact than the sum of its parts was considered.
In this type of generative ideation session it is important to also consider the participants and their background, as that will affect the results. This exercise was conducted with five participants from the ÅSR project with backgrounds in computer sciences, mechanical engineering, physics and management.
While it is obvious that some of the ideas generated in this session were not well defined and highly ambiguous in terms of technological feasibility, it is evident that the platform nature of an autonomous surface vehicle offers extensive opportunities for applications across multiple dimensions.

3.4.4 Considerations on the suitability and performance of autonomous surface vehicles

As discussed in previous sections, the platform nature of autonomous surface vehicles presents a multitude of possibilities for use cases for existing and novel applications. A rational question then is, what are the strengths and limitations of ASVs as platforms for different applications compared to alternative autonomous systems and manned marine conduct? Similarly, it is also important to consider the differences between wind and other propulsion methods within the same dimensions. To support this analysis, two SWOT-analyses for both questions were made visible in the ÅSR project environment and left up for a few days, during which they were collaborative filled. The thoughts generated from the ideas were used to pinpoint topics for discussions with concepts in the coming interviews

Strengths and opportunities

Removing a crew from a surface going vehicle and replacing their tasks with automation provides exciting opportunities. The running costs of the vehicle are reduced even on semi-autonomous and monitored vehicles, as a single operator could oversee several crafts. Additionally, the risks of operating at sea for the crew are also removed. Since there is no need to facilitate for crew and their necessities on board, the size and form factor can be better optimized for the task at hand. Further, autonomous operation can be more cost efficient in smaller crafts, where the cost of the crew amounts to a larger portion of the running costs. However, in longer voyages, such as in international shipping, the cost of the crew can still make up a large portion of the operational costs. ASVs can also be utilized alongside manned missions as a force multiplier for example in environmental monitoring. This could be accomplished with a single or several vehicles deployed at the site, or they could travel to the location beforehand such as in [12].

Limitations and threats

Removing the crew from surface vehicle does however present problems, especially with unseen issues that emerge at sea. These include problems with maintenance and repair. If something breaks or for example gets tangled, there is no crew to respond to the situation and consequently the vessel might become impaired, adrift in the water or even sink. Moreover, a damaged ASV might also put other vessels in danger. Communications to and from the ASVs become restricted if the vehicles venture far from coasts, as the bandwidth for data communication is greatly reduced when operating outside of the cellular networks since satellite communications are required. The development of autonomous surface vehicles faces obstacles in navigation, collision avoidance, complying with COLREGs and facing environmental disturbances. Other less likely scenarios include vandalism and even theft. Particularly cyber theft of information or hacking of the vessel are noteworthy threats of ASVs. Finally, the ongoing development of unmanned aerial vehicles might also turn out to be disruptive for some applications of ASVs.

3.4.5 Wind propulsion for autonomous surface vehicles

No running costs from crew or fuel and essentially unlimited range and deployment period with zero emissions. These would be the main strengths of a fully developed wind propelled autonomous surface vehicle.

When considering the limitations of WPASVs compared to other propulsion alternatives, the inability to compete in speed is among the first considerations. The maximum speed of current small WPASVs from benchmarking is about 5-8 knots and this is directly related to the vessel's size and waterline. Where as any fast motorized boat can theoretically be fitted with an autonomous system that could then exceed speeds of 50+ knots. Furthermore, wind propulsion is also dependent on the variable wind conditions. If there is little to no wind, there is little to no movement of the vessel and even if there is wind it has to be from a favorable direction in relation to the desired heading of the ASV.

However, what WPASV lack in speed, they can make up in endurance. Harvesting energy from the environment with sails offers an almost always present, albeit inconsistent, source of energy for movement. This combined with other means of gathering energy for electronic systems makes is possible to deploy WPASVs for extended periods, notably the Saildrone and SailBuoy enabling missions up to 12 months [9][5]. Since propulsion is provided by wind power, a WPASV could also carry more energy as its cargo compared to vehicles that are propelled via electric or combustion engines. As they have to transport their energy for movement onboard. The ÅSR prototype ASPire utilizes a free rotaring wingsail for propulsion. When compared to traditional sails, wingsails have a higher efficiency, can be self-trimming and require less actuation force [35]. This makes them highly suitable for autonomous long-term deployments.

There are also other methods to utilize wind for propulsion and to harvest energy. Flettner rotors are another simple method that utilizes a tall cylinder that is spun along its long axis and the Magnus effect causes lift that is used to propel a vessel. A more complicated system for wind propulsion is the use of wind kites that are flown from a vessel and need more complicated inputs. In addition to propulsion, wind can be utilized to generate electricity with wind turbines, one such example is the C-Enduro ASV as described in the benchmarking section.[36]

The physics of sailing call for correcting for the momentum from the sail by counteracting the roll of the vessel. With sailboats a keel is most often used for this purpose and consequently the draft of the vessel is increased. Using a deeper keel increases the draft and limits the depth of the water in which the vessel can operate. This limits the possible area of operation, especially in coastal waters. However, this issue can be mitigated by utilizing a multi hull design (catamaran and trimarans), with a telescopic keel or a pivoting keel to provide variable draft. All of these options are common practices in with sailboat designs. Generally, wind propelled surface vehicles are less agile and have less control for movement. As such, WPASVs without additional propulsion or control actuators are underactuated and this presents a challenge for precise control [37].

When discussing wind propulsion, it is also important to consider other options for harvesting environmental energy for propulsion. Wave energy is another method to harvest energy from the environment. The AutoNaut and Wave Glider platforms presented in the benchmarking section are platforms that utilizes wave energy for their movement [16][19].

The lack of noise from propellers also provides a well-suited platform for acoustic listening applications, since background noise is reduced. The reduced noise pollution beneath the surface should also reduce the stress that is exerted to the environment. This might be an advantage for example in environmental fish stock monitoring with sonar, since the fish would likely be less disturbed by the vehicle, resulting in observations in more natural habitat. Another suitable application is PAM monitoring further discussed in the last two interviews of this thesis. The lack of pollution also extends outside of noise pollution. A wind propelled ASV does not pollute with exhaust gasses or motor oils, further reducing its impact on the environment. Many would also consider the silent gliding of a wind propelled craft a more compelling sight. The advantages that could be gained from reduced noise are discussed in 4.4.1 and 4.4.2.

3.4.6 Considering trends

One of the methods for opportunity identification is to consider relevant trends and more importantly their implications [3]. For this reason, some of the current marine related trends were ideated among the ÅSR employees and are documented here.

United nations decade of ocean science

The United Nations recently announced the Decade of Ocean Science for Sustainable Development (2021-2030). The goal of the initiative is to support efforts to reverse the cycle of declining ocean health. The decade is set to begin in January 2021 and UN is currently looking to gather stakeholders for the initiative [38].

Growing concern and interest in microplastics in the oceans

Probably you the reader have at least heard of the massive garbage patches in the Pacific Ocean, where plastics are trapped in ocean currents and slowly decay into smaller pieces. Plastics and more specifically micro plastics have been a source of increasing outrage and concern during the last couple of years and concepts and solutions are being generated on how the oceans could be cleaned. As such ASVs could be a viable option for cleanup efforts.

Fish populations at risk

Another environmental topic that was brought up was the concerns of fish populations due to over fishing and pollution.

Big data analytics

This has been a more prevalent topic concerning privacy issues with our everyday uses of smart phones and other connected devices. With companies seeking to gather and analyze massive amounts of data from multiple sources, the tools that are being developed for these purposes might also be adaptable to the needs in the marine science fields with goals of mapping and better understanding the marine ecosystems.

Ever increasing shipping and offshore energy sector in the oceans

In addition to trade expansions requiring more shipping, the offshore energy sector is also expanding with an emphasis on increasing demand for sustainable energy sources such as wind farms [39]. These developments are going to put a larger strain on the oceans, but also open up new opportunities for autonomous systems for supporting roles.

Automation is here

Different levels of automation are commonplace across manufacturing sectors and with the emergence of autonomous vehicles, it only makes sense that the technology is ripe to also apply in the marine environment. This combined with the increasing cost of human labor makes the prospect of autonomous ocean vessels even more appealing. It was brought up that maintenance activities are still mainly a human effort, so there might be a coming paradigm shift in the role of workers.

Renewable energy from oceans

With the pursuit of establishing more offshore wind farms and utilizing wave energy, these offshore installations could have latent needs for mobile autonomous for maintenance or other applications.

Hacking

If and when the oceans are filled with unmanned vessels for shipping and other applications, surely there is a concern for someone to hack into the merchant ship reconfigure it for nefarious purposes. This could also be true for smaller platforms.

Open source initiatives

As robotics become ever increasingly commonplace and attainable, it is very likely that open source communities will gather around autonomous vessels and might create a need for a platform design. This idea is also somewhat reflected in the ‘Early exploration of the design space’ section of this thesis.

AI

With the constant development of artificial intelligence and self-correcting models a self correcting-model and autonomous vessels are a great combination.

3.5 *Expert interviews for opportunity identification and need-finding*

In order to support the internal product development within the ÅSR project, a series of interviews were conducted with representatives from the project’s partner companies and other outside contacts. The objectives of these interviews varied from opportunity identification, needfinding and gathering expertise on the technological and legal challenges facing the development of autonomous surface vehicles.

3.5.1 Method planning for interviews

Planning of the interviews was done by first recognizing different areas of expertise, from which input should be gathered. Then professionals of the field were sought and requested for an interview. The interviewees consist of some that had been in previous contact with the ÅSR-project and some that were contacted for the first time for the interviews. After the interviewees granted an interview, more specific goals, topics and questions were prepared for that particular interview. The format of the interviews was preferably either face to face or via a video call. This was so that the interviews could have a less rigid structure and interesting ideas could be better recognized and followed during the interviews. This is one of the main reasons that interviews were chosen as a method for the opportunity identification and needfinding activities with the experts. Interview guides were prepared for each interview in a way that the interview questions would approach the goals of the interview by working from ‘outside to inside’. More detail-oriented questions were preceded by broader topics. The reasoning for this flow was to give the interviewee some time to consider the relevance of the broader topics with regard to more detailed questions and using more open-ended questions to precede the sometimes ambiguous topics with no right or wrong answers, a warm-up of sorts. Further, the method was used as an effort to gain a more holistic understanding and context of the possible implications of the more detailed oriented answers.

Even though interview guides with pre-prepared topics and questions were made, the possible shortcoming of strictly adhering to these was that some promising directions would be overlooked and never discovered. This was especially likely in these interviews where the topics and questions of the interview were prepared by an interviewer from outside of the interviewees’ area of expertise. The possibility of not asking the right and most relevant questions, due to lack of understanding or empathy of the interviewees field was high. In preparation for avoiding this problem and ultimately gaining better insights, the topics of the interviews often deviated from the interview guideline, when interesting topics arose during the interviews. However, in an effort to ensure a more holistic covering of all of the interview goals, the interviews were guided in a way that all of the pre-prepared topics were discussed at least on some level, even though this sometimes meant cutting some fruitful conversations short due to time constraints. It is worth noting that due to the novelty of the technology combined with a pursuit for opinions, the answers of the interviewees should not be held as absolutes.

The interviews are presented in the following format. First, the motivations for the general interview topics are reasoned. Followed by a short introduction of the interviewee. Next, the more specific interview topics are explained with their motivations. The contents of the interviews themselves are then recounted. After this the contents of the interviews are then briefly analyzed with the goal of better understanding the implications of the opinions of the experts, with regard to the interview goals and also in the broader context of this thesis.

3.5.2 Master mariner and project initiator, Ronny Eriksson

Designated as [40]

Ronny Eriksson is the initiator of the ÅSR project and was the lead of the project from its early years in 2013. Therefore, it was worth to gather his ideas on the background of the project and possible thoughts on the applications and about general conduct in the shipping industry.

The project begun in 2013 with thoughts on project for the university. From his profession Mr. Eriksson derived issues with shipping and ship owners who are always concerned about fuel costs and personnel costs. For fuel, wind could be used instead, and autonomy could cut costs on personnel. He discovered that others had had similar ideas and communities had developed around small autonomous surface vehicles. In the beginning of the project goals were set for transatlantic crossing, but the motivations were in technology development for robotic sailing. Early work was done with small available remote-controlled sail boats. After a while, funding was gathered for the marine research platform project and the goals shifted onto the development of a marine research platform.

Mr. Eriksson explained that in 2013 the discussion on automatization on vessels was very sparse. In 2014 Rolls Royce promoted autonomous vessels and after that the market and interest dramatically increased across shipping and sailing applications. The shift in thinking has been very fast. Wind propulsion and the suitability of it was then discussed. For ships the speed-energy-curve is exponential, meaning that in order to increase the speed by little, the energy has to be increased a lot. The implications of this are that for wind propulsion applications the speed has to be quite low since wind energy is limited. Designs do exist for fast wind propelled crafts, but if the capacity to carry cargo is desired, then the speed has to be low. With shipping applications, the cargo would have to be low value cargo, or at least promptness of delivery cannot be a high requirement. Other technologies, such as wind kites have been in development for large ships, however they are expensive and complicated to use. Flettner rotors a low maintenance alternative, but they have low efficiency. The wind propulsion is further discussed in the 3.4.5 section of this thesis. Another consideration is generating power from wind and the most efficient method is to use a wind turbine. This could also be used for propulsion through an electric motor, but there are losses in energy conversions. Next the topic shipped into the applications for ASVs and Mr. Eriksson thought that the first ones would be research related data collection activities. However, as this is a new industry and the technology is not yet mature enough to be profitable. As soon as the technological challenges are addressed for the technology to become profitable, at that moment larger companies will have incentives for development and will likely adopt the technology at a much larger scale. If you have means (technology) and an incentive (cost reductions, efficiency), then combining the two for profitable ventures will be highly coveted. Autonomous vessels are a highly disrupting technology and will change the maritime paradigm in the long run. No costs from the crew or fuel, would lower the cost of expansion basically to the cost of the unit. If there were an established pier to pier route, the expansion of that could be done with little effort by simply adding vessels. With this type of system traditional manned ships could not compete, with the exception of expedited delivery with other faster technologies. Further, Mr. Eriksson explained his views that commonly with disruptive technologies people have tendencies to overestimate the timeframe when it is coming and underestimate the impact of the technologies. This has already happened in the sipping sector, where previously crews would be 40-50 people and today the same sized ships are run with crews of 10-12 people as there is a commercial interest for reducing crew costs. An issue with unmanned conduct in the maritime environment is in the juridical side, insurances, owner contracts etc. Many of the contracts and processed used today are very old and the changing of the will be difficult and time consuming. Who takes the risks of liability and other issues need to be addressed.

Discussion

The paradigm shift and the disruptive impacts from the autonomous shipping applications were an interesting conversation. This interview also shed light into the legislative issues in the maritime environment, where rules and regulations have been made for manned ships. The legislation is certainly one of the larger non-technology related issues regarding the use of ASVs and is further discussed in 4.2.

3.5.3 Husö biological station Amanuens – Tony Cederberg

Designated as [41]

For the 2016-2018 ÅSR project a goal had been set to develop a marine research platform for environmental observations. One of the partners in the project is Husö biological station located on the Åland Islands functions under the Åbo Akademi University. Among other research, the station functions as the base for aquatic studies for the University. The station is also part of the network of Finnish Research Stations and the Finnish Marine Research Infrastructure FINMARI [42].

An interview was held with Tony Cederberg, an Amanuens at the station. Goals for the interview were to gather a better understanding of biological research activities, research objectives and equipment that is by the researchers. Further, an area of interest was to understand what types of issues are limiting factors in the stations' research in order to possibly discover applications for ASVs, since it was expected that an unmanned platform might be of interest to reduce the time-consuming work done by researchers.

First, Mr. Cederberg was asked to describe some of the station's activities and history. The research activities of the station have varied over the years since the establishment of the station in 1959, with recent emphasis on shallow bays, introduced species and climate change among other things. A portion of the the research is basic marine and lake research as mandated by the European Union's (EU) water framework directive, since the Åland isles in this regard are considered an independent state with subsequent obligations. Much of the research activities at Husö are for establishing basic understanding of the state of the environment, as they are the only ones doing this type of research in the Åland isles and ground work has to be done for more detailed research activities to take place. Thus far most of their sampling equipment has been quite rudimentary and manual equipment. Examples include manual water 'traps' enabling the gathering samples at different depths and similar equipment for gathering bottom soil samples, which are then analyzed at the station or sent to other laboratories. They have planned to invest in more technology-based equipment in the coming years. The interviewee pointed out that although several new types of products have been introduced to the market in recent years, the high cost and expectations of more advanced and affordable versions of these products that are sure to follow have been the main reasons for waiting on the investments. For biological research novel technologies include Lidar lasers for underwater habitat mapping and the use of airborne methods for optical data gathering for shallow bays. Husö is likely going to acquire a drone for this purpose in the close future.

The high cost of some of the available equipment compared to their performance has also lead Husö station to develop equipment themselves. In recent years the station has conducted vegetative research with a self-made drop video system. The system consists of a submersible part with a camera and optional lights seen in Figure 16. The submersible part is connected to the surface with a tether and a cable that sends live video to monitors that are used to position the camera in the water manually. The camera records video to a memory card as it is towed with the boat from which it is deployed, and the locations and directions of the towing runs are recorded. The traditional alternative for this method is diving, from which more accurate data is produced, but with considerably more effort. The drop video-method is a good way to get large amounts of data from the subsurface habitat fast and with relatively low effort. This is utilized up to 30 meters deep, but generally bellow 10 meters the vegetation becomes very sparse. Other more technological alternatives for gathering information on the state of bottom vegetation include side-scan sonar, that can produce information on the vegetative density, volume and bottom type.

Figure 16: Submersible part of an action camera-based self-made dropvideo system developed by Husö biological station with an image of the bottom [43]

One piece of automated equipment that Husö has as a part of the FINMARI initiative is an automated moored profiling surface buoy, often deployed in the outer archipelago at sites of interest. The buoy is equipped with two-way 3G communication and measures the vertical water column at programmed intervals, typically a few times a day between 4-40 meters with a winch and sends the data back to shore. Different sensors can be equipped and often include dissolved oxygen, chlorophyll, temperature and salinity. A wish for this particular piece of equipment is to improve the user interface for near real time monitoring and visualization. The profiling buoy is a good way to produce data from the water column, but it is highly localized. Manned missions can be used create better resolution, but they are costly and coverage in time is also desired. A sailing robot might be a suitable technology for this need. Generally, the need for more real time data is desired. If the data is offline, then extra work comes from the analysis of the bulk of data that is recovered at once. Other smaller pieces of unmanned technologies utilized by Husö include temperature and light loggers that can be left in the environment to record and data is later recovered.

The gathering of water samples was discussed during the interview. They are gathered for many purposes, some are mandated by EU and others are for general research purposes. Some of the measured parameters, mainly temperature and secchi depth (water visibility) have to be measured at location and dissolved oxygen needs to be stabilized in the sample with chemicals as it will otherwise begin to change. In addition, other parameters; salinity, pH, chorophyll, phosphorous, and nitrogen are measured in a lab. A wish would be to increase the capability to do more of the measurements in-situ. However, the mandated measurements three times a year would still need to be conducted with defined methods and therefore better in-situ sensors could not replace water samples for this purpose. If ASVs could do more in-situ monitoring it would be helpful to reduce the manned labor and generate more ‘background data’ that is currently left undone.

Considerations for ASVs for biological research from Husö’s percpective

From Husö’s perspective acquiring an ASV would depend on the performance and capability of the vessel. Especially, this has to be compared to the cost of manned missions. In order for the investment to be worthwhile, it has to improve on the current methods.

Another consideration of high importance is the ability to modify and expand the capability of the vessel for future work and this ability would make the platform much more desirable. Currently for a small ASV, the acquiring price could be around 100 K € if bought and the cost for a service model, where the platform would be rented, or capability provided with outside missions is difficult to price. It was mentioned that if the station were to acquire an ASV for research use, other stakeholders, such as fishers would likely be interested in the data as well. When asked about suitable payload capacities for an ASV and the OceanAero's 23 kg payload was used as a reference, Mr. Cederberg thought that 23 kg might quickly become too small and a higher capacity would be desired. Currently the buoy described before has a payload of 15 kg for sensors, but additional payload capacity for batteries and control equipment.

Discussion

Based on the interview, ASVs could be used for increasing research capabilities by reducing manned efforts. Since sampling is time consuming with manned missions, it is only used to the needed capacity. Unmanned technologies, such as buoys and loggers can be left to sample the environment, but the results are highly localized. Further, if the equipment is not connected to produce near-real time data the data analysis from the recovered equipment can become a demanding task. Therefore, ASVs with connections to shore could be used to produce more data at a considerably lower effort and both spatial and temporal coverage would be improved on. Suitable technologies for an ASV would include physiochemical sensors, and the capability to lower them to the water column for vertical sampling. Technologies also exist for underwater habitat mapping with the use of Lidar and side-scan sonar that could be equipped into the ASV to gather information on the vegetation and bottom topography. These technologies can be expensive, but for an ASV, the costs might be rational. With more development, collaborative capability of an ASV an unmanned aerial vehicle system would provide enhanced capability. Since some of the mandated monitoring activities require the use of specific methods and technologies, ASVs would not necessarily add value to them. From a cost point of view, the overall cost and capability of an ASV has to improve on the exiting methods and reduce overall costs to be on interest. High cost of technologies is an issue for organizations with limited funding an incentivizes them to innovate solutions for themselves, such as the drop video method described in this interview.

3.5.4 An expert in environmental observations

Designated as [44]

In addition to biological parameters, the physiochemical parameters of the ocean environment, including water and weather are also monitored for various applications. ASVs may present a viable alternative for improving on the existing methods and a better understanding for their use and requirements was desired. For this purpose, an expert in environmental observations was interviewed. The expert has over two decades of experience in both marine and atmospheric observations. In addition, the expert has extensive experience in the hardware and software solutions required for both fields. For this interview the expert wished to remain anonymous.

First topic of the interview was to gather a better understanding of what methods are currently utilized to produce data from the marine environment in the Baltic. Current methods for gathering ocean related data include, wave buoys, profiling buoys, remote sensing with satellites, 'ferrybox' equipment and flow through equipment onboard commercial ferries. Ferryboxes are a type of system, where water is pumped from a sub-surface inlet that is then slightly processed before entering an internal loop, where sensors for different parameters can be installed [45]. Further, the water can be guided through more complicated systems for analyzing biochemical composition. Water samples can be stored for further analysis and the excess water is pumped back to the ocean.

Considerations for a platform for oceanographic use

The topic of a platforms design for scientific research was discussed during the interview. The expert said that modularity for instruments would be the best practice. For a modular design where equipment can be changed, the interfaces within the vessel have to been well thought out. Further, the exchanging of the equipment has to be made simple and established modularity standards should be followed for size, data formats and power needs. The instruments themselves should be acquired from well-established manufacturers. With the ocean environment, problems with calibration drift and biofouling are an issue. With different technologies, the calibration times and susceptibility for biofouling do vary and can cause issues with the quality of the data if some of the sensors are still good and others require maintenance. Methods for preventing biofouling include mechanical wipers, UV-light, anti-fouling paints and electrical currents. Among suitable technologies for ASVs, acoustic doppler profilers (ADCP) were mentioned for current measurements. Also, the use of flow through equipment, where water flows through a section which is equipped with other sensors was suggested. In terms of how the platform provides data for the end users, the method must not be a 'black box' that produces data that has been formatted in a way which the operator does not disclose. I.e. the raw sensor to data has to be made available for the users of the data. This was said to be especially important for serious scientific research that might later be used for legislative purposes. Generally, researchers and other purchasers of oceanographic data are more likely to purchase equipment or data from well-established manufacturers since the future user support is better and the providing company will be in existence for the coming years or decades as they are less likely to go bankrupt.

Limitations and obstacles for autonomous surface vehicles

Ambiguity relating to the legislation for use of ASVs is currently too constraining and consequently too costly. The interviewee clarified that they were not familiar with the current detailed legislation, but a conversation was held on the general prevalent legislative paradigm in the Baltic environment. There are lots of limitations for operating unmanned surface vehicles outside of designated test areas and generally having a visual line of sight is required. If the vessel is remotely piloted a qualified pilot, likely a master mariner, has to oversee the operation 24/7 and the implication of this is that the costs of overseeing a single ASV become too great. A solution for this would be that several platforms are monitored concurrently, thus reducing the operational costs per platform. The goal would be to drive the operational and oversight costs per unit to an acceptable level. With increasing use of ASVs a centralized operations center run by service providers or even by governments could be utilized. Since ASVs currently require supervision, further operational expenses will also come from communications when operated outside of cellular coverage. This is since satellite communications would need to be used and the use of iridium satellites is rather expensive and bandwidth is low. As the issue of costs is ever prevalent in oceanography, the currently utilized methods have already been developed to be cost effective and proven technologies. In order to compete with the existing technology in a commercially viable way, the total costs of ASV operations will either have to reduce the costs or be utilized in niches, where the current models are lacking.

During the interview several more detailed use cases for ASVs were discussed and are categorized here. It is worth noting that additional capability could and should be added where applicable without hindering the original task or raising costs needlessly.

Deployment, retrieval or other interactions with existing equipment

The costs of transporting and deploying equipment in the marine environment have always been high due to the needed personnel, vessels and time and reducing this would be highly desirable. Along the Finnish coast, networks of wave buoys and other surface equipment have to be retrieved and deployed annually due to the ice coverage. In addition to these tasks, maintenance operations are also needed for the bottom mounted equipment thus further increasing the costs of maintaining the equipment. Similarly to buoys, Argo floats have to be manually deployed as they drift with the currents. A higher utilization of the floats is desired, but held back partially due to the costs of deployment and retrieval. In addition, other maintenance operations such as charging deployed equipment would be a possible development direction. One of the use cases for ASVs would be to interact with other deployed equipment. Bottom mounted equipment could be inspected with more periodically, with the use of an acoustic modem or light data transfer closer to the bottom. This would enable more timely systems checks and data download from equipment that is otherwise not connected to shore.

Wave measurements

As mentioned above, the costs of deploying wave buoys is high, 10-20K € per buoy for the larger ones as estimated by the expert. Therefore ‘virtual mooring’ of a wave measuring ASV could be a suitable application. In virtual mooring, the ASV would maintain its position in a designated area and produce real time data. In order to be a worthwhile application, the data quality would have be up to par with the current buoy-based measurements, as their data is used by multiple stakeholders such as ship pilots, whose safety depends on the reliability of the data. The best design for a wave measuring device is a circular shape due to the physics of wave measurements, where the measuring device has to react to the waves. There are GPS and accelerometer-based methods and generally the accelerometer-based methods are more accurate. This would further assert the need for a hull design that would likely be in a conflict with an ASVs capability to sail and maintain position. For shorter measuring campaigns for other research purposes an ASV might be utilized with less accurate results. An ASV for wave measuring tasks via station keeping could also be equipped with other sensors. The expert suggested surface CTD parameters, current profiling and marine weather along with possibilities for modularity. When asked if the expert saw any strengths in a moving platform for wave measurement, they did not see it as particularly helpful for day-to-day observations, since wave measuring campaigns require data from a single location over a longer period of time, but for campaigns it could be useful.

Depth profiles

Data requirements for the basic ocean surface measurements are currently covered with remote sensing (satellites) and established buoy networks. Consequently, better coverage of depth profiles of the water column is highly desired across multiple parameters and stakeholders. At the very least the basic parameters conductivity, temperature and depth (CTD) should be covered. With established methods, more Argo floats could be used for this task. Additionally, gliders are also an option, but they are more work intensive and have higher operating costs than Argo floats. Moreover, gliders do not work well in the 5-50 meter depth range, which covers a large portion of the Baltic. Therefore, a suitable niche for surface vessels would be oceanographic data for this upper water column where other methods are lacking.

Marine weather

A better coverage of marine weather from more points is desired. However expanding the network is difficult, due to issues such as electricity requirements, data transfer connections, ice coverage and maintenance.

Current trends with ASVs

The interviewee had conducted research into the currently available ASV-platforms and explained his views on some of the current trends with the technology. First, there is a paradigm shift to move from complicated and expensive platforms to first choosing the desired equipment types and methods and then a platform that can manage the use of said equipment. The end users are not interested in paying for redundant capability if it is in conflict with the costs of the platform. Interestingly, the platforms might even be less expensive than the equipment that they are equipped with. Regarding the equipment itself, ‘plug and play’ is desired by the market.

Discussion

For day-to-day observations of the marine environment, networks of various connected equipment are used. Wave, wind and current conditions are established with networks of moored buoys that are connected to the shore and procure real-time data for various stakeholders. Bottom mounted instruments are also used to better observe currents. The availability and quality of the data has to be absolute and real-time as it is used to assist in safety related decision making for recreational and commercial use. Additionally, remote sensing technologies are used to observe the top level of the oceans and to produce models of the marine environment in a cost-effective way. The availability of commercial traffic is also utilized for data gathering with equipment that is installed into ferries. For more campaign-oriented data gathering other instruments such as Argo floats and gliders are used as well. The annual ice coverage in the Baltic environment sets limitations to the deployments of the moored instruments as they have to be deployed and retrieved accordingly. These operations are costly require the use of manned vessels. Thus, the concept of ASVs for use instead of buoys is an alluring one as the deployment costs would be much less than the deployment and retrieval of buoys. However, in order to for ASVs to compete against these current methods, they will have to be proven for reliable data production. Additional capability should be added to the ASVs in order to improve their performance. For other uses, such as vertical depth profiles, ASVs are a noteworthy application to improve on the shortcomings of other autonomous vehicles. For use in the close future there are issues with the ambiguity and restrictiveness of the current legislation, that present additional costs from oversight of the unmanned vehicles and this should be addressed with centralized operations.

3.5.5 Naval engineering company ASCE – Tage Lindfors

Designated as [46]

The marine environment presents variable environmental conditions, which are sometime very rough. An ASV has to be able to survive the conditions in which it is deployed and high performance is desired for navigation capability. ASCE, a naval consulting company specializing on stability calculations had previously conducted stability calculations for the ASPire prototype and an interview was held with Tage Lindfors and another representative from the company in order to gain a better understanding of design considerations for small surface vehicles.

Mr. Lindfors began by stating that for a small autonomous sailing ship one of the most important considerations is that the ship is basically unsinkable. This requires a self-righting hull and further that there should not be openings on the deck of the ship, where water might enter. The self-righting abilities for the ASPire are achieved by having enough ballast in the keel. For this interview pictures of the Saildrone, SailBuoy and Ocean Aero were brought as references to discuss the different hull designs and their performance. Generally, a longer ship is steadier than a smaller one which will be fluctuating more from the environmental factors and puts a larger strain on the guidance systems.

For ship and vessel designs, naval architectural programs are used to model the designs and conduct stability calculations. Another consideration is the desired payload capacity (deadweight) and the smaller the vessel is the smaller the payload will be in relation to the total weight of the vessel. Furthermore, smaller designs are more susceptible to issues when overloading the designs. The question of defining the payloads is an issue of optimization that has to be figured out in the very early phases of vessel design. As the use of ASVs for transporting other equipment had been discussed before, a question was presented on how the movement of a vessel changes depending on the loading of it. The width or the beam of a ship is the most important consideration for the stability of a vessel, a higher beam will improve the stability, but in contrast it will also reduce the forward speed of the vessel. A slenderer design will improve the speed but reduce the stability. Furthermore, multi hull designs are great at improving stability, but they risk the highly coveted self-righting capabilities. Whichever the payload, it should be placed midship and as low as possible for best performance. Next suitable practices for small vessel design for high performance with adequate withstanding of adverse conditions was discussed. No magical solutions exist for a design that can do everything. Vessel design is always a compromise and therefore it its highly important to figure out the desired characteristic in the early phases of ship design, whether a higher payload capacity or better maneuverability are desired. Another important consideration is the intended environment. In the Baltic sea the conditions are considerably different from the Atlantic and vice versa. Generally, in the north Atlantic the waves are bigger and longer than in the Baltic, where the waves are smaller and steeper resulting in a higher angle of encounter. For a smaller ship it can be more difficult to maneuver in shallow waters and if the wave length is similar to the vessels length there will be big issues in the ability to navigate, especially for an autonomous system.

Discussion

This interview affirmed the need to specify the intended use cases early on in the designs process of a vessel. If the parameters for desired payload variation are well defined during the early phases, a better performing platform can be engineered. Further, the desired environment should also be defined well, especially for wind propelled ASVs.

3.5.6 Researcher at a solar solution company HelioZenit Ab - Mikael Olsson

Designated as [47]

Whatever the purpose of an autonomous surface vessel, electrical power is needed onboard. One of the partner companies of the ÅSR-project is the Åland based company HelioZenit specializing in solar tracking systems. Mikael Olsson, a researcher from the company had been working with the ÅSR-project in 2016 and 2017 with the design, planning and implementation of the ASPire prototype's power system. Therefore he was requested for an interview regarding power considerations for an ASV. The interview was in the form of an email questionnaire and the answers are presented here in a question-answer format.

Solar as a power source

Question: Of the available solar panel types, which ones do you see as the most suitable for applications in ASVs in the salt-water environment for prolonged deployment?

Answer: All common solar panels use an aluminum frame and glass on top. The aluminum will take a beating over the years due to the salt water, but it won't affect the performance of the panel. The solar cells are well protected by the glass on top and the plastic on the backside. Due to space constrains, high efficiency (mono-crystalline) panels are preferrable, such as LG Neon 2, BenQ Sunforte or SunPower. These have 20-21% efficiencies compared with ordinary panels with 15-17% efficiencies. These HQ panels cost 30% more per watt.

Q: Is utilizing solar panels for energy at sea different from utilizing them at land, e.g. reflections etc?

A: The utilization is the same at sea as on land: the panel(s) are connected to a solar battery regulator which in turn connects to a battery array. However, at sea the panels *are typically placed flat and not optimized towards the sun as in the case of fixed installations on land. Flat panels get more cosine losses than south facing tilted panels, to the tune of 0-20% less energy depending on the latitude. The higher the latitude, the more it pays to tilt the panels, whereas on the equator a flat panel is the ideal. There are also sources of shade at sea that may be unavoidable, such as shading from the sail/mast.*

Q: How considerable are the differences in available solar energy depending on the time of year and location and is this difference directly proportional to the amount of energy that can be harvested with solar panels?

A: *There's a direct relation between the amount of sunshine (light hours/year) and the energy yield. 5-10% of the solar energy comes in as diffuse sunlight reflected from the ground and atmosphere, but the bulk of the energy comes from direct sunlight hitting the panels.*
The higher the latitude the larger the difference becomes. Here in the south of Finland 80% of the solar energy comes in during the summer half of the year, and less than 1% during Dec-Jan. The further south you go the less seasonal variation you get. The seasonal differences near the equator are far less noticeable.

Application types, flat or curved panels

Q: Many of the suitable areas for solar panels on sailing vessel can be single or double curved surfaces (for example along the wingsail), is this an issue, or is it a requirement to have flat surfaces for panels?
Is there an increase in cost and weight and reduction in efficiency when using multiple smaller panels versus one big panel?

A: We considered using flexible panels on the wing sail instead of the more common framed type of panels. Since the wing sail would have to rotate 360+ degrees this became needlessly complex so we opted for the hull mounted panel instead. Ideally, each solar module should have the same amount of sunlight, hence the flat panel is the best in terms of performance. Flexible panels have slightly less efficiencies overall, and when placed on a curved surface the part of the module with the least amount of solar intensity will reduce the yield also for the part of the module receiving more solar intensity. So if there's much of a curve multiple rows of separate modules will give better performance than a single curved module. The weight of flexible panels is low and otherwise unusable parts of the vessel can be utilized so it's a very good idea to use flexible panels if more power is needed.

Maintenance needs

Q: Do you think that the use of solar panels on ASVs at sea presents some special maintenance or operational requirements?

A: Solar panels are extremely low maintenance compared with other means of generating power. In places with heavy pollution or sandstorms you need to clean them, but not even that would be necessary for an ASV-mounted panel.
The batteries however need to be kept from being completely drained as a discharged battery left alone depletes its lifetime in a matter of weeks.

Advantages and challenges

Q: How to you see solar powers advantages and limitations compared to other available power sources at seas, e.g. waves and wind?

A: Wind turbines are a good complement to solar panels at sea, since unlike panels, turbines can generate power throughout the day. A single turbine is more space-efficient than a panel, but unlike solar you cannot place multiple turbines close to each other. You won't get a lot of power from a small turbine and the power will vary greatly with the wind speed and wind turbulence. Turbines also require a lot of maintenance, more so than any other mainstream way of generating energy. The turbine can be connected to the same battery array as the solar panels, with a wind-charge controller in-between. I haven't tried wave power, only wind. We considered using a small vertical axis wind turbine for ASPire, but space and weight constraints meant we decided not to.

Gathering and utilizing power

Q: Previously it was planned that the ASPire could have a solar tracking system, could you explain a little about the opportunities and limitations for its implementation? For example, do you think that the motion of the vessels with the waves be a large issue?

A: Since my primary field of expertise is solar tracking systems Anna suggested we try building and evaluating a solar tracker for the ASPire, as a potential product for mobile applications. There were no technical challenges to this, and I built a prototype fairly quickly. However, there were two issues with using a solar tracker at sea: weight and cost. Whereas a fixed panel lay flat on the hull of the boat, a tracking panel needs free space around it for it to tilt and rotate. For a small boat such as the ASPire this extra weight and wind resistance would affect the maneuverability of the boat negatively.
The second issue was cost. Many of the costs for a solar tracking system are fixed. Regardless of whether you track a framework with a single 50-watt panel or a 2000-watt panel array you still need the same control electronics, GPS module, position sensor, and motor. At 50€, these fixed costs are negligible for a large solar tracker, but for our small 50-watt panel costing 50€ it's was not cost-effective in terms of making a product out of it. The energy increase per year from tracking the sun at sea would be 30-70% depending on the latitude, compared with a flat panel.

Q: What do you think are the best battery storage options for the harvested solar energy?

A: We used a Victron 12V 110Ah deep cycle GEL battery for the ASPire, the same kind of battery typically used for home solar energy storage. GEL batteries require no maintenance, other than keeping them from being completely discharged. They have longer design lives (12 years) and lose less max capacity per charge/discharge cycle compared with the two other common lead-acid battery types, floating batteries and AGM. In turn, they cost more.
If we had need for more energy storage we would have used a lithium battery instead (LiFePO4). They still cost 3-4 times more than GEL per kWh, but you can fit 2.5 kWh with the same volume and weight (30 kg) as the 1 kWh GEL battery (theoretically 1.3 kWh but using more than 1 kWh will wear down the battery more quickly). Also, the lithium battery allows use of 100% of the energy capacity for 2000 cycles until 20% of the

max capacity is lost. In comparison, a Victron GEL battery discharged to 20% would last only 500 cycles until 20% of the max capacity was lost.

Power practices on a wind propelled autonomous surface vessel

Q: Previously you had worked on the power system on the ASPire. What do you think are good energy saving practises for such a system that is dependant on its stored energy when deployed, and that it can harvest from the environment?

A: We discussed these issues, but we never ran into energy constraints so it wasn't a priority. If a long term test was conducted the vessel would have to keep close track of its energy budget and be able to switch off any non-vital subsystems as needed to conserve power. If energy supplies are expected to run critical, without any sunshine or wind in sight, the vessel could go into maintain-position-mode, send an alert to its home station, or return to port. For an ASV, conservation of energy is more important than producing more of it. It's the low hanging fruit. It's much easier to reduce the energy consumption of a system by an order of magnitude, than it is to add 10 times more solar panels and wind turbines to the vessel. The ASPire had many subsystems such as the GPS module, a latern, the AIS, the control system for the mast, and the camera for collision avoidance.

Discussion

Based on this interview, the wide use of solar panels seen on the benchmarked platforms, especially the ones that harvest energy from wind and wave power, is well reasoned. Solar panels provide means of generating power in a robust and low maintenance way. Furthermore, their integration to the system is straightforward. In the Baltic environment at higher latitudes, additional systems for tracking could be means to improve the available energy with low effort if the additional space for the implementation is available.

3.5.7 Loss prevention manager at naval insurance company Alandia Marine – Lars Janlöv

Designated as [48]

The use of unmanned vessels alongside manned ones causes corners for liability issues regarding the possibility of accidents. In addition, the legislation for the use of ASVs is still lacking. A loss prevention manager Lars Janlöv was interviewed concerning the current practices for marine insurances, liability for damages and future concerns for autonomous vessels. Much of the conversation was on the current insurance practices, insurance types and claim distributions in relation to causes. The levels of automation in vessels have increased in the past 25 years and the number of claims in relation to insured objects has reduced, this indicated that the marine conduct has become safer. However, interestingly the distributions for causes for claims has remained similar. Human errors are often behind causes for insurance claims in nautical errors and one of the prevalent issues in fatigue of the crew.
Today there are no systems being utilized that make independent decisions for navigation, but rather automation is used to aid the human decision making. The next big step is likely

in artificial intelligence, where the decision making is shifted to the machine at some capacity. This is the cause of discussion in across different fields, who is liable when the decision making is moved to the machines? Both authorities and the industries are working on the issue on figuring out where the liability is shifted as someone has to be liable. No clear answers exist yet. Mr. Janlöv explained that the first thing to do for an insurance is for the owner to do a risk assessment. If the risks need to be covered, then they will go to an insurance company and ask if they are willing to share it with them for a premium. This is the basic concept for all insurances. As the risks are still largely unknown, since there is no historical background data the risks and their weights are difficult to assess. Legislation usually follows technology development, but the industry is trying to work with authorities to expedite the process. International autonomous shipping is far away, and most trials will take place in national waters, where legislative hurdles are easier to get around for the trials. Finally, Mr. Janlöv was asked if he thinks that the rules might change for manned vessels as well, since in the future they will be sailing alongside fully autonomous ships with independent decision making. He thought that if such artificial intelligence reaches the shipping sector, at that point it has already taken over other fields and the society as a whole will have changed so therefore speculating only on the shipping aspects is an inadequate approach.

Discussion

Ambiguity surrounds the questions of liability issues for autonomous unmanned vessels in several dimensions. First, the issues of who is responsible if something were to happen need to be addressed. Second, due to the novelty of the technology the risks are also largely unknown. Third, as the legislation that insurance practices need to follow does not allow for unmanned conduct of vessels move on their own power , it is impossible for the insurance industry to get a head start in insuring ASVs. Furthermore, if the completely autonomous systems with independent decision making for all scenarios reach the shipping sector, likely other impacts to society as a whole have been introduced at that point.

4 Choosing a design direction

At this point of the process it was decided to embrace the design direction of a modular platform for marine sciences for the rest of the thesis work. Several promising ideas had been discovered from benchmarking and interviews. A discussion was held with the ÅSR project manager regarding the findings with regard to the broader goals of the project. The goal had been set to research and develop a marine research platform for the 2016-2018 project and the research findings of this thesis work thus far support that design direction as highly viable. It is important to note however, that concentrating on the marine research platform as a design direction does not exclude the use of a modular platform for uses in other science- and business sectors, since the capability of a platform can be altered with the included equipment. Additionally, marine sciences have strong existing needs and incentives for improving methods, broadening data gathering capabilities and cutting costs. Several manufacturers have also embraced the idea and are currently operating and proving their platform's capabilities as reviewed in the benchmarking section. All of these needs also imply strong opportunities for viable business models, which is also a goal of the project. When discussing this design direction with the project manager, other points were made that in addition to existing interest, scientists and researchers in the marine field are willing and motivated to adopt new technologies. Further, it could be speculated that they also have a high technical ability to adopt complicated systems since many are already in use. Researchers are also already accustomed to utilizing expensive equipment, as platforms and installations costing hundreds of thousands of euros are being and have been utilized for a long time.

The theory on the diffusion of innovations divides the adopters of novel innovations into five adopter categories. The second adopter category *early adopters* are likely to search for new ideas, have favorable attitudes towards them and poses the available resources to adopt them. Additionally, this adopter group poses the ability and are willing to adopt new innovations at higher costs than the later groups [49]. In the case of ASVs researchers can be considered to be the early adopters of the technology.

In the field of use of autonomous vessels in the marine environment, meeting user needs with technical capability is not the only obstacle to overcome. Legislation or lack thereof is a major issue for viable commercial ventures and it makes sense to first concentrate on applications where stakeholders are limited. From the point of view of the operations of autonomous surface vehicles, marine sciences have a smaller stakeholder group as for example shipping applications. For the opportunity identification it was important to review other proposed and tested use-cases as well, since they had not been explored with detail during the project. Further, a literature review was done with the aim of reviewing what else autonomous surface vehicles could and have been be used for. In addition, ideation methods were used to further investigate and ideate applications for ASVs.

4.1 ***System level needs***

As explored in the benchmarking section of this thesis, ASVs come in various sizes, shapes and configurations. Regardless of the design of an ASV, in order to function as an autonomous or unmanned system with guidance, several technologies are needed and challenges have to be addressed before the ASV can be considered functional. The required technologies and their implementation results in the high levels needs or the 'must haves' before an ASV could be used for any other purpose. The implementation and challenges are not within the scope of this thesis, but the required elements are briefly listed here in order to provide a more comprehensive understanding of the technology requirements. Liu et al [37] present a comprehensive literature review of the development and challenges for USVs (ASVs).

They categorize the crucial elements of an USV system into six categories:

1. *Hull and auxiliary structural elements*
   Different variations for the general size and outlook of ASVs exist and have been implemented. These include rigid inflatable hulls, single hull kayaks, twin hull catamarans and triple hull trimarans with different strengths and limitations for each design.

2. *Propulsion and power systems:*
   Heading and speed control is provided by the propulsion and power system. Different approaches exist for the control of the vessel. In the ASPire prototype a freely rotating wingsail is used in conjunction with a rudder to control the vessel. Other propulsion methods include 'rudder and propeller' and differential thrust via two independent propellers. All of these methods provide under actuated control, meaning that the available control actuators are less than the degrees of freedom of the vessel. Fully and over actuated ASVs are possible, but increase costs.

3. *Guidance navigation control (GNC) systems:*
   Typically consist of an onboard computer and related software. The GNC systems are the most important component of an ASV as they are in charge of the entire system. A general GNC structure is seen in Figure 17.

4. *Communications systems:*
   These include communications to and from ground stations, other vessels and other equipment with wireless communication. In addition communications are needed within the ASV for sensors and actuators.

5. *Data collection equipment:*
   This category consist of equipment such as GPS, sonars, radar and cameras that provide information for the control of the ASV, as well as monitoring of the ASVs status. In addition, this category includes specific equipment for the intended purpose of the ASV, such as environmental sensors.

6. *Ground station:*
   Ground stations are needed to provide additional control and mission planning for the ASV. Ground stations can be located onshore or onboard manned ships, where status of the ASV is monitored and changes can be made wirelessly.

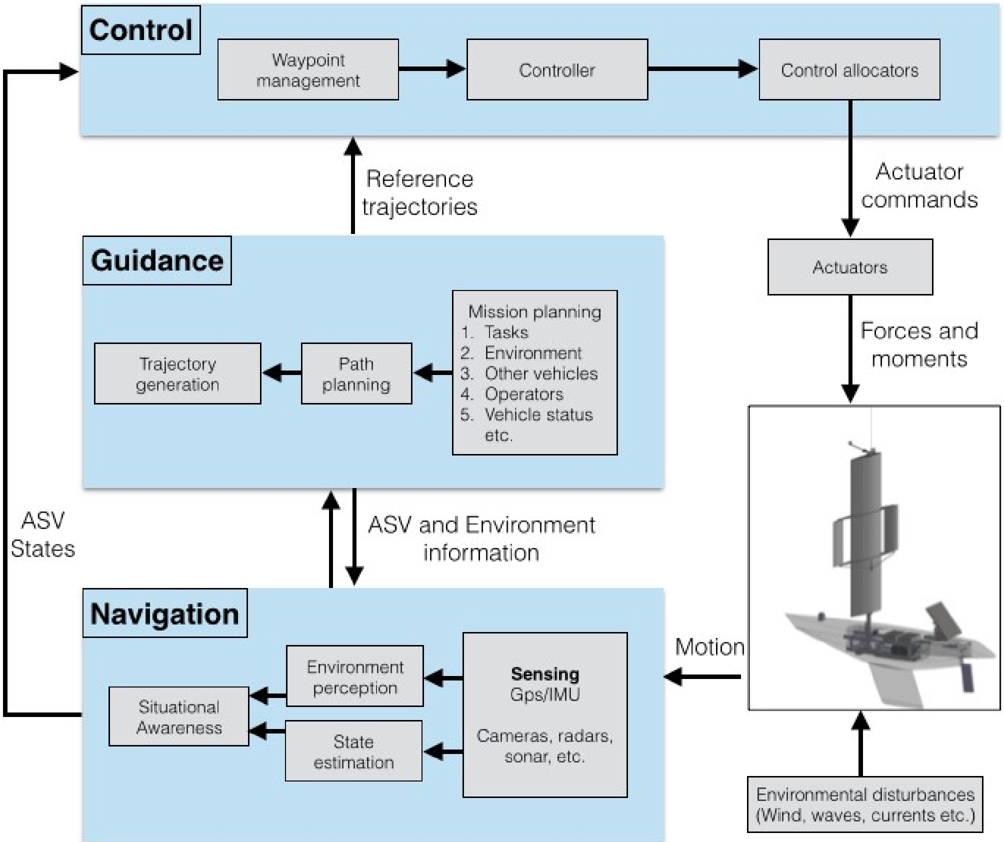


Figure 17: General ASV GNC systems [37]

Research in the ÅSR-project has addressed these categories and their implementation the ASPire prototype is descried in various other documentations in the project's website's 'documents' and 'publications' [50].

4.2 *Regulations regarding the use of ASVs*

The issues of legality regarding the use of ASVs has been mentioned several times in this thesis and are covered in short detail in this section. The technology requirements for ASVs are not the only consideration for different applications, the maritime regulations are old and have been made with manned conduct in mind. The use of unmanned vessels presents issues with liability questions and safety concerns. A recent thesis explores the regulatory work and current state of regulatory issues [51]. The maritime regulations are restricting the wider implementation of ASVs, but work has begun on adapting the regulations for unmanned vehicles. The International Maritime Organization recently started an exercise for reviewing the needs to amend the regulations for international maritime regulations, but there is still a long way to go before unmanned vessel can become commonplace.

UK Maritime Autonomous Systems Working Group (MASRWG) recently published a code of practice for Maritime Autonomous Surface Ships (MASS) in November 2017, which was updated to version 2 in November 2018 [52]. This code of practice seeks to provide initial standards for different considerations for the manufacturers of MASS under 24 meters. The standards are intended for the interim period while the more specific standards are established. A multitude of classifications and definitions will have to be established and regulatory work will have to be created for defining rules and regulations of what kind of ASVs can be used and how. From the perspective of autonomy, different levels of control are possible with an operator either controlling or overseeing the vessel. For this purpose, different categorizations have been made and one of the more notable ones is the European Defence Agency's Safety and Regulations for European Unmanned Maritime Systems (SARUMS) group's categorization.

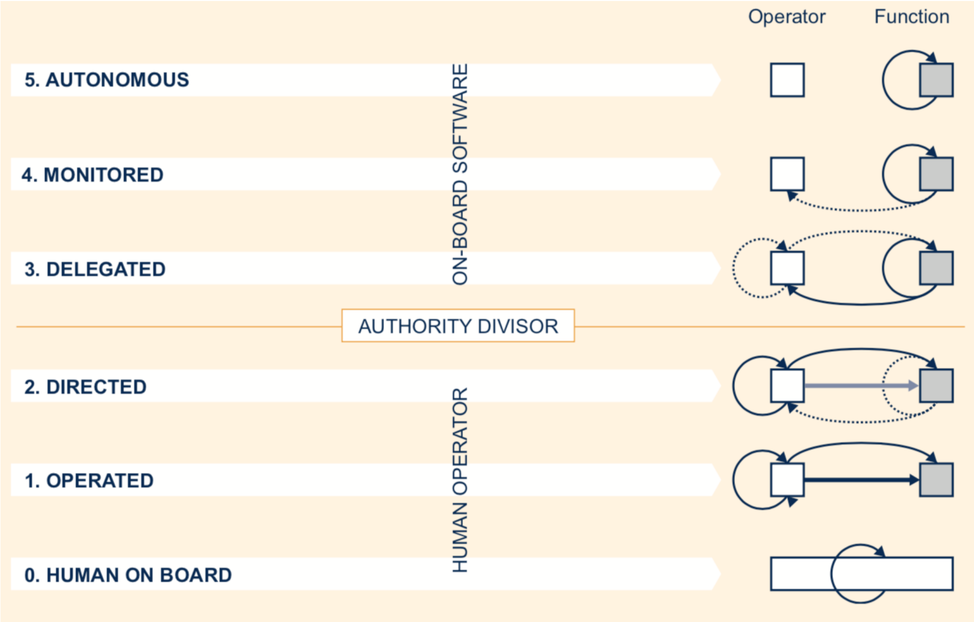


Figure 18: Six levels of control and authority division [52]

Level	Name	Description
0	Manned	Vessel is controlled by humans aboard
1	Operated	Under operated control by an operator. The operator has direct control over the craft, this can be via radio control, a cable etc. All decisions and functions are made by the operator.
2	Directed	Under direct control, but the vessel can suggest one or several operations by sensing the environment and its state. The vessel will only act when the operator prompts or permits it to do so.
3	Delegated	The vessel is authorized to execute some functions. The vessel can sense its environment and plan decisions that it will communicate to the operator. The operator has the ability to veto the decisions that the vessel is going to make during some time and if the operator does not do so, the vessel will act on its own.
4	Monitored	The vessel defines and makes decisions on its own based on its own senses and reports its state and intentions. The operator can oversee the actions and events.

5	Autonomous	The vessel will sense its environment, plan and implement actions on its own. The vessel it programmed to make decisions within its technical capability. The decision making is independent and the vessel does not have to notify external parties.

Table 8: Levels of control definitions [52]

A key component for legislation for the use of ASVs is to establish standards for different classes of ASVs. Classes will have to be established for various criteria such as intended use, areas of operation, situational awareness etc. From the viewpoint or other vessels, one of the most basic ones is the size and the speed of the ASVs. The UK Maritime Autonomous Systems Working Group proposes a classification based on these criteria.

Class of MASS	Characteristics
Ultra-light	Length overall <7m and maximum speed <4kts
Light	Length overall ≥ 7m to <12m and maximum speed <7kts
Small	Length overall ≥ 12m to <24m
Large	Length ≥24m (and 100 Gross Tonnage)
High speed	Operating speed V is not less than V = 7.19 ∇1⁄6 knots. ∇ = moulded displacement, in m^3, of the craft corresponding to the design waterline

Table 9: Classifications for maritime autonomous surface ships as proposed by MASRWG [52]

The code of practice goes on defining objectives, abilities and design considerations at length. Since with each needed classification, different configurations can be created, the task of defining classifications is immense.

International regulations are more restricting than national ones and United Nations Convention on the Law of the Sea provide states sovereignty in their territorial waters. This allows for less restricted rules for testing of ASVs within territorial waters [51]
High motivations for expediting the resolving of legislative issues come from the shipping industry, which is keen on resolving the regulatory issues for future autonomous shipping. A Finish collaboration One Sea is an ecosystem that is pursuing the goal of creating an operational autonomous maritime ecosystem by 2025 [53]. For the collaboration a test area is being established in southern Finland for all interested companies to conduct testing. Similarly, a test area also exists in Norway in Oslofjord at Horten [54].

4.3 *Modularity ideation workshop*

With the design direction of focusing on applications for marine sciences via a modular platform, an ideation workshop was held in order to recognize and ideate possible problems and opportunities in a platform that is designed for varied use. These ideas and concepts could then be used for gathering feedback and as a means to gain empathy on technical and user related challenges in the marine sciences for the coming interviews in the marine sciences fields. The participants of the workshop consisted of the facilitator (author) and five attendees, all of who had some previous experience with at least the general concept of autonomous surface vehicles.

This one-day workshop consisted of two parts. The first part was a participatory design thinking lecture, in which the basics of design thinking methodology were presented and experimented with via a 'design the ideal wallet for your partner'-exercise that was interweaved to the lecture. In the exercise the participants applied a five-step process of Emphatize-Define-Ideate-Prototype-Test for developing an ideal wallet for someone other than themself. This lecture and exercise were included to the workshop day in order to warm up for the second part of the workshop where the goals were to define and ideate possible issues with a platform design, in which the capability of the platform could be altered via equipment changes. Methods and format of the workshop consisted of a participatory lecture, facilitated ideation methods, brainstorming, interdisciplinary group work challenges and rapid prototyping as detailed bellow.

What might be the challenges?

First activity of the modularity workshop was to brainstorm and list issues that might be of concern when considering a platform design where interchangeability of equipment would be *possible, inviting, accommodating and high performing*. In addition, the inverse was also discussed; what are the strengths of such a concept? This topic was approached with an open discussion, where the facilitator listed the discussed categories onto a white board. The 'Issues' and 'Strengths' are detailed bellow in no particular order.

<u>Issues:</u>

- Manufacturer compatibility
    - Different manufactures utilize different protocols, connectors and other design choice and accommodating for this diversity in a practical way might cause difficult design constraints.
- Stability of vessel
    - If and when the platforms weight and its distribution are changed, the navigation performance are altered. This issue will be further amplified due to the autonomous navigation of an ASV.
- Size
    - The equipment utilized in marine sciences comes in all different sizes and shapes and accommodating for this range in a way where space is neither wasted nor exhausted is another design issue.
- Mounting
    - Similar to the size, the mounting or securing of equipment used in a given configuration needs to be adequate and designed for to avoid awkward clusters of equipment zip-tied together.

- Servicing
    - Marine sensors and other equipment need periodical maintenance in order to assure reliable data and prolong the life of the equipment.
- Calibration requirements
    - Measuring equipment should be calibrated prior and periodically during use and a platform in where this activity is straightforward is another advantage for the users.
- Power requirements
    - The power requirements of an ASV vary across equipment and intended use. Conserving and replenishing the available electrical power are important practices for prolonged use.
- Protocols
    - Different manufactures and sensor types utilize different protocols for communications.
- Connectors
    - Similarly as above, the connector types utilized by manufacturers vary.
- Leaks
    - Leak prevention is an important topic for surface vessels. Different issues caused by improper sealing include, loss of vessel, condensation and short circuits. The possibility of leaks is especially likely when the design calls for interchangeability of equipment that is both in contact with the environment and the hull of the vessel.
- Data storage
    - Since the data formats and capacity requirements of sensors vary across equipment and intended use, adequate storage must be available when needed.

<u>Strengths:</u>

- Variety for choice
    - When it comes to marine sensors and other sampling equipment, there are often several, even dozens of alternatives for a given parameter or combinations of those.
- Standardized modules
    - Although there is variety in the design choices of manufacturers, it is also true that efforts have been made for standardization.
- Brand loyalty
    - Larger manufacturers offer equipment for various uses with good compatibility and data handling solutions.
- Science community
    - The science community was seen as an able community with, the skills and ability to ensure performance in their fields.
- Sturdy designs
    - Decades of ocean and atmospheric sciences have already produced sturdy and reliable designs for the marine environment.

After a group discussion of these issues and strengths two were selected for further ideation and refinement. These categories were selected based on the perceived importance and good expectations for suitability of the workshop setting and likelihood for meaningful results with the given time and expertise. The combined issue of leak prevention and equipment management was the first category. The second was the broader category of facilitating for maintenance activities of the end users as a good design in this category was seen as a way to stand out from the competition.

Leak prevention and equipment management

Questioning how might we prevent leaking or eliminating the problems that they might cause was the next phase of the workshop. In this exercise the goal was to ideate numerous ideas for how to prevent leaks that might be caused by the sensors that would be mounted to the vessels and later replaced by another. Furthermore, the challenge of utilizing a design that makes leaking risks a non-issue was emphasized in the design pitch. After ideating several ideas, the most promising ones would be further developed through prototyping. The format of this phase was again open brainstorming with an emphasis on visual communication of ideas through drawing. Props such as cardboard boxes and other available materials were used to further communicate the problems. Rough ideas or concepts were generated and drawn by the facilitator. Bizarre ideas were highly welcome in this phase as they might spark new concepts in this group generation method.

The ideas are listed below with and the resulting drawing in seen in Figure 19

‘Panels’

- This idea relies on ready made and sized panels, which seal onto the hull of the vessel with confidence and into which the sensors could be mounted without having to make alterations into the actual hull of the vessel. The panels could be relatively inexpensive and could be stored for further use if a given configuration of sensors would be needed in the future.

‘Catamaran’

- The ‘Catamaran’ idea is to utilize a smaller secondary hull into which equipment would be mounted. These hulls could be customized for detailed tasks or act as multi purpose. This idea does not tackle the leak prevention objectives, but it does mitigate and isolate the damages to the sensor area in the case of a leak. Further, this idea offers an interesting idea for achieving specialized capability with a removable configuration.

‘Hole’

- The ‘Hole’ is a concept where a vertical inlet is created through the hull and the waterline of the vessel and the sensors would be mounted or hanging in contact with water. The concept takes advantage of the existing robust and waterproof equipment that is already available. Cabling would still need to be let through the hull at some point, but it could be done above the waterline.

‘Isolation’

- In ‘Isolation’ the sensors would be mounted in an isolated compartment of the vessel and data (and power) communications would utilize wireless connections to eliminate issues from breaches of the connection between the sensor and the hull.

‘Balloons’

- This concept is more of survival mechanism in which the available void spaces would be filled with balloons (like in a ball pit), thus ensuring that in the event of a hull breach the vessel would at least not sink due to the positive buoyancy created by the balloons.

‘Self seal’

- This concept is inspired by the self sealing tires in vehicles, where in the event of a leak, the hole is patched by glue-like material that is already inside the tire. This concept could utilize a double hull and a chemical reaction with water to seal a leak.

‘Pump’

- Tried and true survival method in the case of excess water entering the hull of a vessel.

‘Winch’

- Much like in the ‘Hole’-idea the mounting of sensors into a winch that can be lowered to the water, thus eliminating concerns about water entering the hull. Could also be utilized in conjunction with the ‘Hole’-idea to achieve a favorable lowering point to the water, especially for towing applications.

‘It’s already sunken’

- Fill the thing with water to begin with and drive it under the water.

‘Custom seals’

- Fabricating customized seals for equipment that would be mounted into ready made inlets in the hull.

After the ideation phase, the ideas were reviewed and discussed with the participants of the workshop. Then in order to categorize which of the ideas were seen as best ways to prevent leaks, multivoting was used. The multivoting was done by giving each participant three points that they could give to the concepts freely. The idea that received the most points was the ‘Hole’ with 9 votes and the second was ‘Isolation’ with five votes.

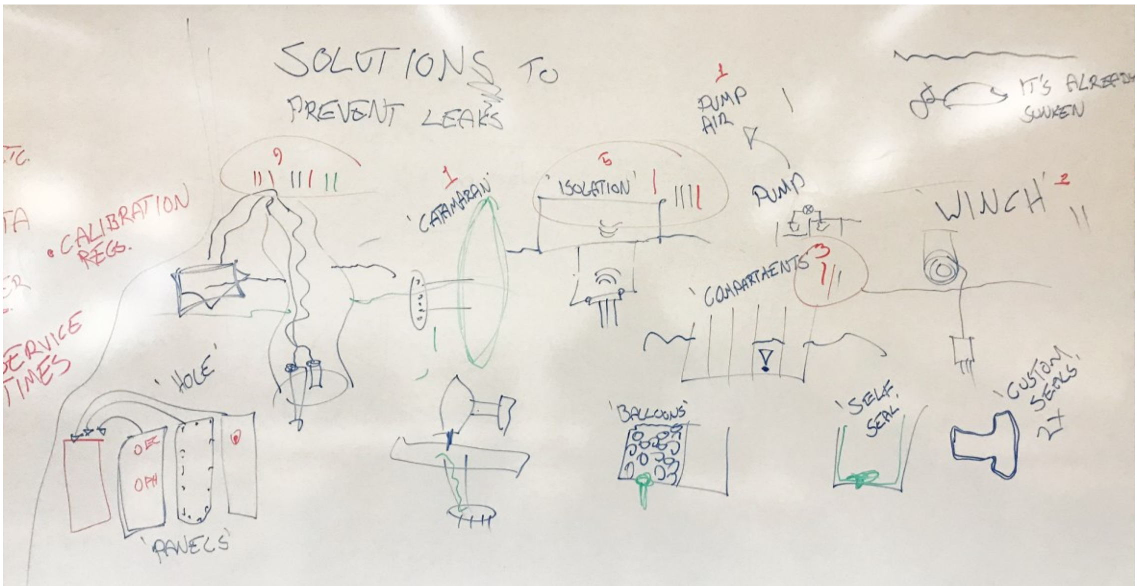


Figure 19: Original drawings of the leak prevention ideation on a whiteboard

What might it look like?

The last part of the workshop consisted of a design task, in which the participants were divided into two groups and were given a task to ideate around the design in question, by defining the problem, ideating solutions that would address the problems and finally create a rapid prototype of what the solution might look like. After the creation of the prototypes, both groups explained their designs and the ideas behind them.

Group 1: A hole through the hull

Design question: *What are challenges in mounting sensors onboard an ASV and how might we prevent and overcome those?*

Challenges for facilitating for interchangeability of sensors that were documented by the first group included:

- The sensor is sometimes under water
- Which cable is which?
- Sensors might be in the mast and thus hard to access
- Reaching cabled, removing them and attaching them
- Heavy sensors?
- Shapes of the sensors
- Complicated attachment points

Ideas were then generated on the possible solutions to the issues as seen in Figure 20

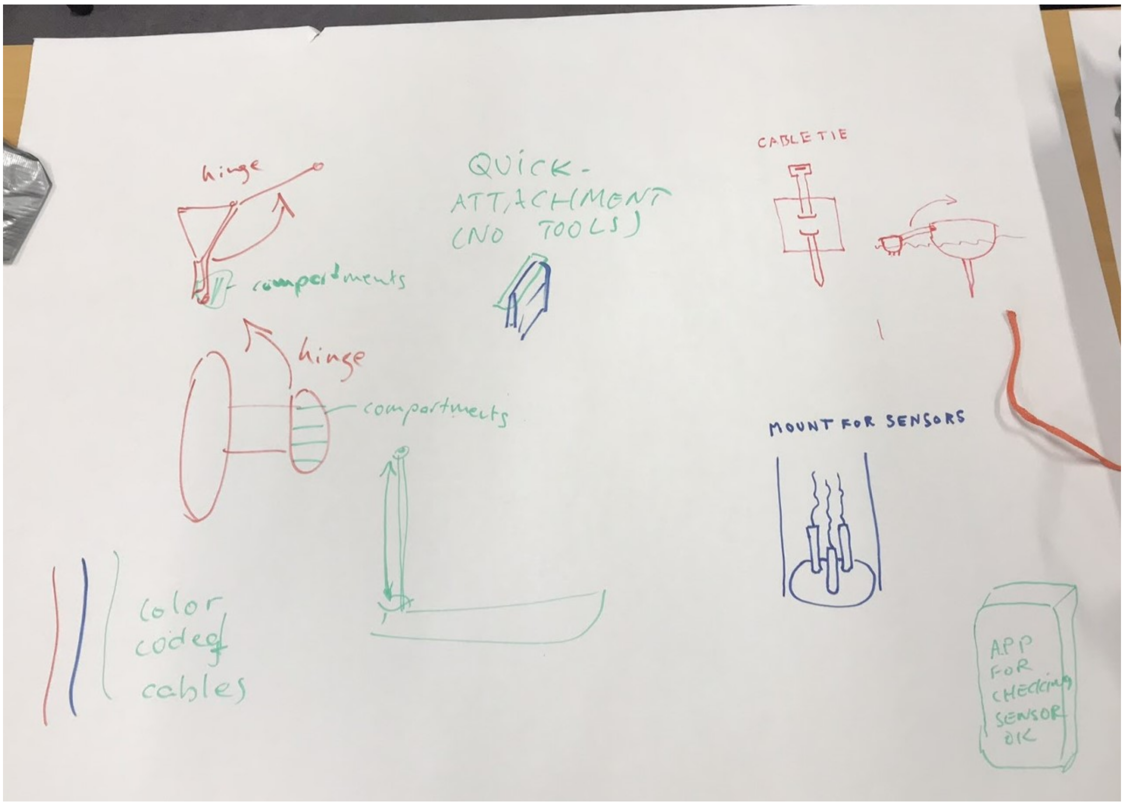


Figure 20: Notes from group number one for sensor mounting options

For the prototype, the first group ended up building on the idea of the 'Hole' from previous ideation. The prototype 'sensor pipe' is a concept for facilitating the contact between sensor and water via a vertical cavity within the vessel's hull. The thinking is that when sensor configurations are changed, there is a probability of leaks is of concern if the sensors are mounted directly into the hull of the vessels. Instead the prototype utilizes a 'hole' through the hull at the bottom of which the sensors could be mounted, thus eliminating the need for variable inlets that can cause concerns with waterproofness. The prototype seen in Figure 21and Figure 22 consists of a cardboard tube as a stand in for the hole through the hull. In the hole, a sensor represented by a white plastic cup with an integrated temperature sensor is dangled with an orange string that can be used to change the height of the mounting. Additionally, a transparent plastic box is used as a rain/splash cover.

Figure 21: The 'Sensor pipe' prototype during the presentation between the groups

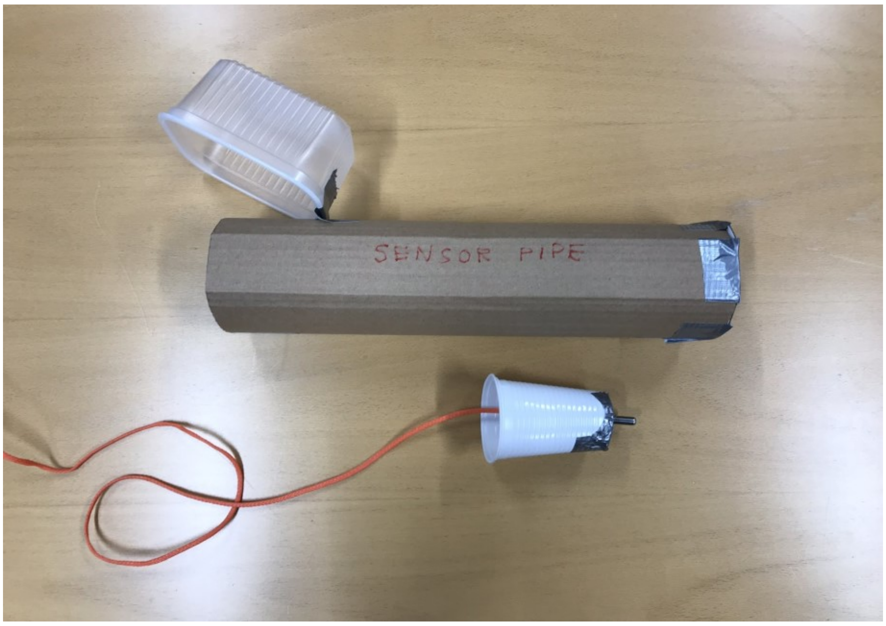


Figure 22: Another picture of the 'sensor pipe' prototype with the sensor head (white) removed

Group 2: Facilating for users

Design question: *What are challenges in maintenance operations and how might we improve them?*

The second group listed servicing concerns with general issues and issued from the actual servicer's perspective:

General:

- Robustness
  - A design has to be such that it can withstand multiple servicing runs
- Access
  - The design should accommodate for access to the related areas
- General cleanliness
  - How are the wires ran etc.
- Calibration
  - Calibration procedures of manufacturers
- Mounting
  - How is the equipment mounted in the design?
- Connectivity test
  - Is everything connected as it should be after servicing?
- Operations test
  - How do you know that the servicing was successful?

Servicer:

- Time
  - Man hours are always of concern
- Reliability
  -
- Procedures
  - Manufacturers have established procedures for the maintenance of their equipment and the design should facilitate for those
- Safety
  - Possible safety issues include sharp edges, electricity, heavy loads
- Tools
  - What tools are needed for the servicing operations?

After generating these lists of possible issues an ideation phase followed where concepts were possible solutions for addressing the issues were generated. These included an automated sensor head calibration unit that would be fitted to a sensor head and would automatically clean, calibrate and test the calibration via wireless communications with the vessels. Other ideas were ideated for similar servicing tools that would aid the servicer of the platform. Further, with this exploration general design guidelines such as color and shape coding the wire, instruments and other parts of the vessel that would be subject to servicing were seen as possible ideas for aiding the servicer.

For the prototype the group ended up building a prototype of a concept named 'Sampling unit', seen in Figure 23 and Figure 24. This prototype consist of a central unit that mounts to the hull of the vessel for power and data needs and includes a wire which runs to the actual sensor head of the unit. The concept is that sampling units could install to the vessel with a modular connection that is both foolproof and user friendly. These objectives are accomplished with color-coded connections that only connect in a single orientation. Similarly, the actual sensor head would be connected with a color-coded wire to aid in tracing and connecting the unit. An oversized handle (clear plastic tape) is added to aid confident handling of the unit when placing it to and from the hull of the vessel. If needed, the unit could be made ready to run outside of the vessels before the straightforward installation. The idea behind this was that the changing of equipment could be done more easily even in field conditions. The deeper meaning for choosing this prototype was to probe the concept of modularity and interchangeable units as a means to try to facilitate for the people that would be configuring the units.

Figure 23: The sampling unit (white) can be removed from the housing (brown)

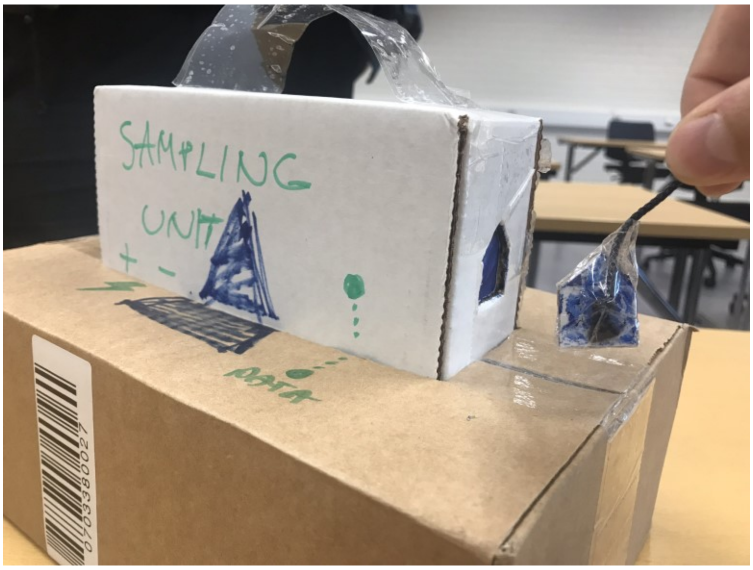


Figure 24: The prototype includes color and shape coding that can be only assembled in one way and proper installation is visually communicated

Discussion on the workshop

Despite the limited time for the workshop, many areas of interests were covered and some of the further takeaways from the workshop are discussed here.

User oriented mechanical- and visual design were recognized as possible ways to positively stand out in the saturating market of different platforms for marine sciences. Further research should be conducted to the maintenance needs and practices for equipment in differed fields and user testing with further concepts would be a means to further pursue the focus of serving the hands-on needs of the users. The focus on the ease maintenance and changing equipment with an inviting design would also decrease the downtime of the vessels.

During the ideation for the 'Leak prevention and equipment management' phase, the concept of larger modules, such as additional hull parts was explored. They were seen as a ways to expand the capability of an ASV for marine sciences. A takeaway from this ideation is that modular solutions that would have an impact on the platform's ability to sail and navigate should be recognized early on in the design of the vessel. This is so that the effects of solutions could be taken into consideration in the early work of stability and navigation analyses of a platform design.

An important shortcoming of the workshop is that despite efforts, no professional marine scientists attended the workshop and therefore the empathy work for defining and evaluating issues in the fields was done from an outside perspective. Therefore the in future work, the ideas should be validated with a professional from the field. Nevertheless, at least the two prototypes that were generated utilized mechanical problem-solving and more universal design practices that could be build upon in detailed concept generation phases of a platform design.

4.4 *Further interviews for marine research applications*

Two more interviews were conducted with efforts to gather feedback on previous ideas and to gain a better understanding about the field of marine researchers. Efforts were made to conduct additional interviews from more fields of research but unfortunately could not be arranged for this thesis.

4.4.1 Director of Cornell University Bioacoustics Research Program –Holger Klinck, Ph.D.

Designated as [55]

For wind propelled autonomous surface vehicles, the assumption had been that passive acoustic monitoring would be a notable application due to the quietness of the platform compared to motorized crafts. The monitoring of harbor porpoise in the Baltic had been proposed within the ÅSR project several times. In order to gain a better understanding of PAM, Dr. Holger Klinck was interviewed.

Dr. Klinck is the Director of Cornell University Bioacoustics Research Program, holds Adjunct Assistant Professor position at Oregon State University (OSU), where he leads the Research Collective for Applied Acoustics. He is a full member of the Acoustical Society of America (ASA), responsible for the ASA technical committee Animal Bioacoustics website and based on the interview an extremely knowledgeable authority in the field of bioacoustics.

The goals of the interview were to gain a better understanding of how and why passive acoustic monitoring is used for biological research. In addition to discussing the possibility of using ASVs for PAM, an important topic was to also understand current methods, in order to evaluate how surface vehicles might compare to them. Costs of PAM and how do they stack up were an important topic regarding the current methods. More technical aspects, such as power requirements, sampling parameters and data handling were also needed. Finally, the last main topic was on what makes for a great platform for PAM applications and how those might be met in an ASV.

Motivations for bioacoustics and historical context

First Dr. Klinck was asked to talk about the motivations, methods and some historical context for the use of passive acoustic for marine research. In his research group the emphasis is on the applied side of passive acoustics, for figuring out when and where animals occur and how human activities might overlap with them. Anthropologic activities such as naval sonar exercises, shipping and offshore construction can cause problems for marine animals and figuring out when and where they occur is essential for protection activities and mitigating the possible impacts from those activities. Especially for marine mammals, what was typically done decades ago was to conduct visual surveys with manned ships by driving in a grid pattern and recording sightings of whales and other animals. This method is of course expensive, but can give a good spatial coverage, however temporal resolution (coverage in time) is limited as surveys could only be conducted infrequently. Furthermore, some whale species are underwater for extended periods of time and cannot be spotted from the surface unless you happen to be there at the right time. The use of passive acoustics for a better temporal coverage, begun two-three decades ago and that is when the field started to emerge. The use of underwater recorders that are mounted to the sea floor and listen for extended periods of time is the prevalent method for long term listening. The use of acoustics offers several advantages, species are easier to identify based on their vocalizations and PAM is a highly non-invasive method of studying their actions. However, issues also exist as many animals are not vocal all the time, or for example the Baleen whales, their song is only vocalized by the males and therefore you are only sampling half the population with passive acoustics. Other drawbacks can come from the need to use high sampling rates for animals that vocalize in high frequencies, thus producing high amounts of data, often in the order of terabytes. Animals that vocalize in higher frequencies, such as dolphins and porpoise, the sound will only travel in the order of hundreds of meters, whereas lower frequency vocalizations from larger whale species can travel be heard sometimes for hundreds of kilometers. For example, the harbor porpoises' vocalizations only travel around 500 meters, so the listening device has to be within this range in order to record the animal, thus decreasing the spatial coverage of underwater recorders.

Therefore, methods for moving the acoustic sensors have been developed in order to better figure out where the animals are. Unmanned technologies that have been used regularly In Dr. Klinck's work include AUVs and gliders. In his research, they have developed systems that can dive down to 1000 meters and ziczac through the ocean while listening and typically after 4-5 hours surface and report back what was recorded during the last dive. This provides a near real time information on the occurrence of animals. Dr. Klinck explained that gliders work well in the deeper oceans but are not suited for shallower waters due to their energy inefficiency in shallow waters. Furthermore, excess noise is produced by their operation in shallow areas. This added with the short detection range of the harbor porpoise means that other better suited technologies are desired for this particular species. Therefore, AVSs might be a suitable method and wind propelled ASVs in particular since they have advantage in being quiet for the most part. Another advantage over gliders is range, typically gliders can cover maybe 20-25 kilometers per day, whereas an ASV could cover much more. In Dr. Knlinck's work with PAM bioacoustics, there is a sweet spot for hydrophone towing applications around 3-5 knots in his opinion as otherwise the flow noise will become excessive and keeping the hydrophone submerged becomes difficult.

Sensors and methods

Next topic of the interview was a more detailed description of the equipment that is used for passive acoustics. The main sensor is a hydrophone, basically an underwater microphone that is simply a piezo-element that converts pressure into a voltage. There can be a single hydrophone or several hydrophones in different arrays, especially when used during manned ship missions where arrays are towed behind the vessel. The hydrophones produce analog signals (voltages) which typically then go through a pre-amplifier that amplifies the signal to a certain level that is then fed into a digitalization system, basically an acoustic recorder. After digitization, there are two options, either store the data into a storage media (SSD, HDD, SD-card, etc.) or analyze the data in real time as it comes in. One of the advantages of ASVs is that you would have constant communications to shore for critical mitigations measurements for example.

The use of hydrophone arrays was mentioned and further explanations for why they might be used over single hydrophones were asked from Dr. Klinck. With a single hydrophone you only have the ability to tell if an animal is preset or not. By utilizing multiple hydrophones, 'target motion analysis' becomes possible. If the instruments are moving faster than the animal, the signals from the vocalizations are received at different times and by knowing the parameters of the equipment (propagation speed of sound, distance and orientation of hydrophones in relation to each other, speed and bearing of the platform that is utilized) bearing angles can be calculated for the direction where the vocalizations are coming from. If the instruments are being moved and the animal is stationary, the consecutive bearing angles can be used to determine where they intersect and consequently the distance to the animal can be calculated. With a line array where hydrophones are attached in a line back to back with some distance in between, there will be ambiguity in to the direction (left or right), but you can determine two bearing angles for the possible locations. The ambiguity can be reduced with more complicated arrays. With multiple hydrophones much more information can be gathered for research, with more advanced methods such as probability detection functions which can be further analyzed for density estimations. Further advantages can be obtained with signal processing, that is called beamforming, which allows steering of the beam that you are listening to, which basically improves the signal to noise ratio for the detection, further improving the research abilities.

Use of prevalent platforms

Next topic of discussion was to further understand the use and deployment of current methods for PAM in bioacoustics with marine mammals. The two most commonly used PAM systems are towed systems in large arrays from large manned ships and the other is the use of stationary systems. With the towed arrays, typically visual surveys are conducted concurrently and problems include the difficulty of detecting some species due to the high noise that is emitted by the vessel. The stationary equipment is basically taken to the site and dumped in the ocean, where it will remain typically for months while recording continuously or intermittently. Some buoys can and have been equipped with real time communications, but this is not mainstream for cost and need related reasons. These two methods (stationary devices and manned towing) have been used for decades and the use of mobile unmanned platforms started around 10 years ago, with gliders and floats. The persistence of the gliders and floats is not as good as the stationary equipment, with gliders achieving around 2 months of deployment with Dr. Klinck's research group's equipment after which batteries are depleted as space is an issue. For floats that function similarly to Argo floats, the deployment period is even shorter as they have even more limited space. The floats are deployed with an educated guess on ocean currents and then they sink to a certain depth and drift with currents. After deployment they will have to be recovered. Gliders also have to be deployed, but not necessarily at the research location as they can be glided to the location. Instead a few people can deploy then outside of the harbor with a small vessel. From a cost point of view, the floats are much cheaper than gliders. Dr. Klinck could not give precise costs due to variables and the costs described in this interview are his estimates. Acoustic gliders typically cost around USD 150,000 and floats around 20 % of that. Gliders typically utilize a single sensor, but stereo options are also used. Some military purposes also use small towed arrays behind gliders for better spatial resolution but their complexity and issues with balance make them needlessly complex for research purposes when research questions involve figuring out when and where animals occur. With unmanned surface vessels persistence can be higher than with floats or gliders as they have higher payload capacity and can be equipped to generate power. However, a problem is that you are stuck in the surface layer of the ocean and thus they might not be the best suited for some species that vocalize in the deeper parts of the oceans. Another type of unmanned equipment are sonar buoys commonly used for submarine tracking in military applications. The sonar buoys are typically deployed in groups from airplanes or vessels and as they parachute down and hit the water's surface, a small hanging hydrophone is deployed and a balloon inflates to keep the rest afloat. Radio signals are then sent by the buoys to vessels or planes for monitoring for submarine activity. These sonar buoys have fixed expiration dates and the U.S. military often provides the expired equipment for research purposes.

Proposing uses and methods for AVSs

After establishing a better understanding of common methods, next goals of the interview were to understand how ASVs could be used for passive acoustic monitoring. The conversation began with how towed hydrophones could be used with small ASVs. Generally the problems with acoustics is that on a moving platform you want to get separation between the platform and the hydrophone. This usually means towing the hydrophone or hydrophone arrays behind the vessel in order to reduce the noise from the platform. Another consideration is depth, as surface noise also affects the use of hydrophones. Depth of several metes is desired and a common practice is to use a downrigger to keep the equipment at a fixed depth. For smaller vessels issues arise from the drag of the line. Especially with sailboats the maneuverability becomes an issue and the location of the line's attachment point has to be defined well. If it is attached to the back of the vessel it will become very difficult to turn. With motors this is not as big of an issue as with sailboats. Another consideration for reducing drag is to use as thin lines as possible, this is both for maintaining speed and maneuverability. This was thought about before the interview and the use of a winch that would deploy the hydrophones at a certain location and conduct a survey before retracting the hydrophone was proposed. Dr. Klinck explained that winches are often used with larger vessels and if the vessels stops the towed arrays will have to be brought in so that it won't get caught in the propellers. For a smaller vessel, he thought it could indeed be possible to have a hydrophone that would be deployed only at the survey location to improve control and speed during other times. Further descriptions of winch equipment were asked and Dr. Holger explained that typically the lines can be Kevlar reinforced and there are two leads inside the reinforcements. The thickness of the cable can be quite thin and it could be made to fit for a small winch.

One of the applications that Dr. Klinck had interest in for the use of ASVs was to use them with an acoustic modem to monitor underwater equipment. They utilize sea floor mounted equipment that can remain in the sea floor for long periods of time and as long as the equipment is down there, the information that it gathers cannot be used. Furthermore, it is impossible to know if the equipment is still operational. As such, one application would be to utilize an underwater modem to communicate between an ASV and underwater equipment to download data or conduct systems checks.

Another use case that was recognized before the interview was the use of ASVs to deploy and retrieve equipment and Dr. Klinck's thoughts on this were asked about. Indeed he thought that could be possible, but size limitations for smaller sailing vehicles could become an issue. The sonar buoys that they were using were thought to be probably too large (approx. 25cm diameter) for small sailing ASV, but the buoys could be deployed at an area and the ASV could receive the radio signals from them and could provide communications to shore or crunch the data at the location.

Since it was previously recognized that vertical CTD-profiles would be useful and ASVs have station keeping abilities, it was asked if there would be any opportunities in lowering a hydrophone down to depths and listening while keeping the ASV more or less stationary. This question was also proposed since for a small ASV towing is difficult but hanging a hydrophone might actually be a good direction, since it would actually aid in the station keeping of the surface vehicle. Dr. Klinck was quite enthusiastic about the idea and proposed that the ASV could be moved to a location and a hydrophone would be deployed to 100 meters for at least 24 hours to gather a daily cycle before hoisting the hydrophone back and moving on the next location. The added cable would need a larger winch with a larger footprint on the vessel but should not be an issue. He also thought the movement of the boat would not be too large of an issue, even a few kilometers would be acceptable over the 24 hour period for their needs (whale bioacoustics) as sound propagates efficiently underwater. With this information the next question was on what would be suitable depths for hydrophone deployments and what advantages are there in deeper deployments? He explained that for his work there are several advantages. It typically gets quieter the deeper you go thus increasing the listening radius, but you don't need to go too deep. 100 meters would probably suffice to get the advantages from the reduced noise. Another advantage for marine mammal bioacoustics would be that sometimes the soundscape of the oceans is crowded with very vocal animals such as dolphins and vocalizations from less vocal animals such as beaked whales are lost in the cacophony. What has been used is a vertical line array of two hydrophones, for example at 100 and 110 meters to get vertical bearing angles. As dolphins are not deep divers, their vocalizations would have upward bearing angles and beaked whales that dive deeper would have downward bearing angles. This method has been effective in isolating the deeper vocalizing animals from the surface animals.

Costs of passive acoustics

Another important topic when considering the use of ASVs is the costs compared to other methods. Dr. Klinck gave some estimates for how the costs stack up for their research. For towed surveys, the vessels will be the biggest cost, a small one around USD 5000-10,000 per day and a really big one can easily be USD 50,000 per day. For this reason towed arrays are used less frequently. With gliders, there is a cost in deploying them with a manned mission, but the higher costs come from the pilot. Typically, as the glider is in the water the pilot checks on it every four hours and that person has to be around to make sure that the glider is doing what it is supposed to. Depending on who is doing the piloting, grad students or technicians, the costs vary. Furthermore, the costs depend on the area of operation. The bottom moored instruments that they are using cost around USD 20,000-40,000 annually to get the equipment down to the bottom and recover it. Surprisingly, for Dr. Klinck's research group's work, the real cost is in the data analysis. Especially for multispecies analysis the analysis is very time consuming and human involved and costlier than the data gathering. On manned missions parts of the data analysis can be done in real time with an operator flagging vocalizations in real time. With deployed instruments without communications terabytes of data are received at once, when the equipment is retrieved and has to be then analyzed. Dr. Klinck went on to explain data analysis methods at length, but that is not discussed here. However, few important points are made. Data analysis can include automated tools and the use of those can be improved with a better platform design, thus cutting costs of the analysis. The most important part is to cut down on the excess noise in order to produce cleaner data, reduce the noise from the signal. This can be done by isolating the hydrophone from the rest of the vessel as much as possible and with towing applications moving the hydrophone deeper to the water to prevent surface noise.

Platform requirements for PAM

If PAM were to be used onboard an ASV, information was desired on the suitable requirements for size, electrical- and storage requirements, as well as issues with long term deployment. Dr. Klinck explained for autonomous platforms all of the size, weight, and volume is typically in the batteries that are required to keep the equipment operational for long periods of time. The electronics themselves are tiny, negligible even. The requirements come down to power requirements and ASVs that can produce power have a big advantage here. Because of charging capabilities, the footprint of a PAM-system can be reduced to be very small. The hydrophones are small as well around the size of a 10 cm tall cylinder with a 3 cm diameter. Further, Dr. Klinck explained that people are building skinny arrays for use in small surface vehicles that have very low drag. The power requirements of a basic PAM system are quite small as well. The equipment the research group is using for deployed applications require around 300-350 mW for recording continuously at 200 KHz sampling rate at 24 bit resolution. Generally, most single channel systems require less than half a watt of power. Multi-channel systems and real time data processing will increase the power needs into a range of few watts, enabling the use of low power processors and detection algorithms. Not all algorithms are equal and other methods require more power.

Biofouling can be an issue with PAM. For example in shallow waters in the US east coast, after six months the biofouling interferes with the recordings and barnacles will have to be scraped from the hydrophone manually. Generally, warm and high productivity environments are more prone to biofouling. Another issue that was asked about is calibration for acoustic measurements. The need for calibration depends on the use, but for example for measuring ocean ambient sound levels, the instruments are calibrated prior and after deployment.

What makes for a good platform

Finally, a more open-ended topic of 'what makes for a great platform' was discussed. Dr. Klinck was asked how he might outfit an empty compartment for the use for passive acoustics on an ASV: *"I think that being able to accommodate different people with different systems is key. So everyone wants to use their system and they have special requirements. So being able to have access to kind of a compartment, where you could implement your stuff, that would be hugely helpful and you would need power there and you would hopefully have an interface to the communications systems, so you can receive and transmit messages and then also have information to GPS so you can time synchronize the system with the rest of the sensors. Easy access to those 3 things, power, communications and GPS, that's pretty much all you would need to be able to implement it."* Next it was discussed why and how these requirements could and should be met. Interfaces for power and communications would not be a big issue and could be accommodated for easily. An ideal WPASV platform in Dr. Klinck's view would be able to tow an array at reasonable distance from the platform with speeds of around 3-5 knots. For efficiency the platform should make use of a wide range of wind speeds. The platform should also survive a sea state 6 wind speeds, which do happen on occasion. One of the more important design considerations is being quiet. The system should be dampened from the platform and the platform itself should be made quiet by dampening its parts also. Another important consideration is persistence, ideally several months at a time and for this purpose the ability to generate power would be a suitable approach as well. Size requirements for PAM would be around a few liters. This is only for the recording system and assumes that the vessel has power and communications already.

4.4.2 Senior Specialist at Turku University of Applied Sciences – Olli Loisa, MSc

Designated as [56]

Further interviews were desired regarding marine research in the Baltic Sea and from the perspective of a person with experience in field research. With the idea of a modular platform design it was important to discuss the strengths and limitations of a re-configurable platform's design with a person with expertise and experience in planning and using different water quality instruments.

Mr. Olli Loisa works with the Turku University of Applied Sciences as a Senior Specialist and a Researcher. His competences include; Marine mammal studies, Non-native species studies, Research development and innovation competence, Sustainable development, Marine engineering, Aquatic technology, Multi use and protection of water systems, Aquatic and environmental research among others. Mr. Loisa has also been involved with PAM-research in the Baltic Sea and other hands-on activities in the field as a researcher.

Mr. Loisa was interviewed regarding the topics of passive acoustic monitoring needs and activities in the Baltic, prolonged deployment of water quality sensors, good scientific practices for marine research and user needs of an autonomous marine research platform.

Topic: Passive acoustic monitoring in the Baltic Sea

The first topic of the interview was passive acoustic monitoring (PAM) activities in the Baltic Sea. Mr. Loisa recounted different PAM-related activities currently ongoing include harbor porpoise, Figure 25, monitoring research activities in the waters of Finland, Sweden, Germany, Denmark and other coastal countries. The equipment for their research activities consist mainly of 'loggers' that listen, recognize and log the echolocation clicks emitted by the harbor porpoise. So loggers do not necessarily record the actual sound, but rather recognize and log the characteristics of the event. These loggers have a very low power consumption for this reason. Mr. Loisa explained that there is a planned project for mapping out the occurrence and density of harbor porpoises in entire Baltic that should begin in the close future, possibly next year. For other biological applications, the evaluation of fish populations in relation to noise was also mentioned and improved methods are currently under development. Mr. Loisa explained that for biological noise related research topics, one of the most important ones is to research how noise affects the marine animals. He explained that it is difficult to evaluate the effects caused by noise to the animals and further what roles do anthropologic noise sources have.

Figure 25: The Harbor porpoise, *Phocoena phocoena* [57]

Another type of acoustic research in the Baltic is the monitoring and characterization of anthropologic noise in the 'Baltic Sea Information on the Acoustic Soundscape' or BIAS-project which is now at and end, but some of the equipment is still use. The research on this project was done mainly with broadband hydrophones that record lower frequencies with the goal of assessing the underwater noise caused by human activities such as shipping or pipelines. The broadband hydrophones record the frequency range of the human ear and some of the ultrasonic range. In Finland few points are still being monitored from the project and lots of noise maps have been produced from the project for the Baltic region.

When asked about the types of platforms in that are being utilized for the acoustic equipment, Mr. Loisa explained that the dominant method is to use bottom moored installations and he was not aware of any mobile platforms being utilized for research, other than possibly some testing. The use of real time data is still quite uncommon and the data is recorded offline and later retrieved. Deployment periods of the acoustic equipment vary from weeks to months and are dependent on the duration of the batteries and available memory. The possible deployment period can also be altered by changes in the duty-cycle of the equipment by for example only monitoring for a certain period of an hour. Later when questions were asked about the deployment costs of moored installations, Mr. Loisa explained that the costs do vary depending on who deploys the equipment and where it is to be deployed, but generally it is indeed rather expensive to go out there, but it can be cost effective depending on how often the spot needs to be visited for maintenance and other reasons. The cost effectiveness was in comparison to utilizing ASVs, since the cost of a single ASV can be very high, when compared to relatively inexpensive hydrophones.

Next topic was on the use of ASVs for PAM-activities. When asked what he thought about the suitability and possible use cases for PAM with ASVs, Mr. Loisa explained that with the relatively low density of harbor porpoise in the Baltic, ASVs might not be a suitable platform at least for density estimations. However, if the question were that whether a given area has harbor porpoise sounds a mobile platform could be a suitable method. Further, he mentioned that despite interest, the over 80 m deep regions of the Baltic is mainly unmapped for the occurrences of harbor porpoises and for that task a towed hydrophone could be utilized in theory. Similarly to Dr. Klinck's comments in the previous interview Mr. Loisa mentioned concerns with surface noise and noise produced by the platform as issues to address in the towing method. Other issues with towing, or 'hanging' PAM equipment would also come from physical boundary layers in the water column. During the summer months the Baltic has a thermocline, meaning a boundary surface between different water temperatures, at around 15-20 meters and if accuracy in acoustic observations is desired, observations should be done under the thermocline, as it strongly affect the propagation of sound. Similarly, a halocline (a strong gradient in salinity) exists at around 60-80 meters. The effects of the halocline are not as strong as the summer thermocline, but it does still affect the propagation of sound under water. Mr. Loisa emphasized that the thermocline is very strong and in addition to the surface noise it is maybe the most important phenomena to take into consideration for acoustic observations. This is since sound is reflected and dampened at the boundary layer. In addition, both halocline and thermocline work differently in other oceans and bodies of water since salinity and temperature are the main acting forces in water density and vary around the world. When discussing the possibility of lowering a hydrophone with a winch to and under these boundary layers, the sampling of other parameters also came up. Again depth profiles for CTD in the watercolum came up and Mr. Loisa affirmed that for depth profiles that would likely be the first application. An important factor would be to have a sensor for depth with the lowered equipment and not simply rely on measuring the line that has been deployed.

Topic: Prolonged deployment of water quality sensors

The second main topic of the interview was concerns in long-term deployment of marine sensors. First, Mr. Loisa was asked to tell about general concerns with longer deployments in the under water environment. He explained that depending on the type of sensors the drifting of calibration, calibration periods and biofouling are of concern. Another concern is the representation of the measured parameter in relation to the research question. For example in a flowing river, the reading of the sensor can come from a very small point and whether that exact point is a good representation for the research question has to be thought out well before addressing other more technical issues. Further, understanding the environment is important for the selection of sensors, for example murky water can cause issues with some technologies. This was said to be a very broad topic and outside the scope of the interview. On the bright side of things, other sensors for example quality CTD-equipment has been already been developed to be very reliable when used correctly. Biofouling and some sensor characteristics can cause the data to start to drift over time and it is highly important to know the equipment and its limitations. Calibration of equipment might be maintained for long periods of time, but if the sensor head begins to develop film or other issues from biofouling the measurements can become unreliable. Next topic was to discuss prevention methods for calibration and biofouling issues. Again Mr. Loisa emphasized the importance of knowing your equipment and its limitations for calibration and the representativeness of the sample. For biofouling different methods such as, mechanical wipers and anti-biofouling paints can be utilized. A method for reducing biofouling in bottom-mounted buoys with vertical profiling capability is to lower the sensors under the boundary layers discussed before. For example, when biofouling is at its worst during algae production the sensors can be parked at higher depths of 30-40 meters. However, this method is not very suitable for a mobile platform.

Next topic of discussion was on how might you know that your data is becoming unreliable? This was for real-time or near real time data, for example from a surface buoy with communications. Mr. Loisa explained: *"There are a few good options, but the visualization of data is a good option. From that a trained eye that knows what should be happening can tell the most coarse faults immediately, and then automatic alarms can be made, meaning that some algorithm follows the material and if it has too low or high or results, concentrations that should not be there. Or then if there is clearly observable crawling development, that too can be in theory can be programmed to be recognized for the warning threshold. But yeah, visualization and automated quality assurance. They are the main methods for that issue. (translated)"*

Topic: Gathering physical water samples with ASVs

Since the need to gather water samples for further laboratory analysis had been discussed in previous interviews, the prospect of utilizing ASVs for the purpose was discussed. Mr. Loisa commented that legislative concerns exist even with the current established continuous monitoring methods due to lack of standardization. Due to this issue, governmental entities or the EU water framework directive cannot accept the data for their use with non-standardized methods. Mr. Loisa explained that the gathering of water samples is also much more involved than one might expect and the person gathering the samples need to have a high professional skill for acquiring representative samples and unmonitored sampling can easily cause issues in the representativeness of the sample. However, in his opinion the standardization of the continuous monitoring methods is coming and will replace at least some of the current methods in the future. There is a lot of legislation and bureaucracy hindering that progress.

Topic: Modular marine research platform and user needs

The last topic of the interview was related to the platform design and possible features for modular use. First the interviewer explained that to his knowledge most of the notable ASV platforms are currently based on the idea that sensors configurations can be altered and configured to fit the platform and different intended use cases. Mr. Loisa also thought that the modularity is a good design objective. Next the discussion turned to how this objective could be met and what would be the main considerations for a modular platform intended for scientific use. Again, ASVs were not Mr. Loisa's area of expertise and thus he was not too familiar with the technology, but he speculated on some of the requirements for such a platform. In order to first have the ability to alter the sensor configurations, the need for power and data storage options were first concerns. After that continuous monitoring activities with connectivity could be thought about. The groundwork would also require choosing the right sensors for the representativeness of measurements in relation to the research questions and those should be made to function with the platform. Further, the environment would case concerns with moisture and waterproofness. For research purposes, the ground requirements, such as power and seaworthiness should be made to be absolutely operational and reliable before worrying about measuring new parameters.

Next question involved the idea of utilizing racks or other solutions to which equipment could be mounted and then the configured rack would be installed into the vessel instead of installing the sensors to the vessel directly. Mr. Loisa though that that could be a suitable design, since if the list of equipment intended for used with the platform was long, it could become difficult to have a ‘one size fits all’ solution inside the vessel itself. Further, modularity might also included alterations to the vessels hull itself, for example with elongating sections. This is a practice that is being used with glider configurations, where the body of the glider can be altered. Next question was on Mr. Loisa’s opinions on how much space would be required for the sensor configurations. He could not give accurate estimates, as that would vary with the use. However, in general loggers and sensors might not require that much space and might even be outside of the platform and batteries might be one of the bigger concerns with space requirements.

Finally, some questions were presented on what might be the software requirements for oversight, guidance and sensor configurations for an ASV. Topics relating to the specific strengths and limitations of wind propulsion were also discussed. As these topics and answers were rather speculative they were not included in this documentation. One of the strengths of wind propulsion might be that the lower noise would be suitable for passive acoustics.

5 Discussion

In this last section of the thesis, suggestions for design directions are created, the process and results are reflected on and suggestions for future work are made.

In addition to ideation and of novel use cases for ASVs in an open-minded manner in the opportunity identification sections of this thesis, the existing and proposed use cases from literature and manufacturers were also explored. Some of the available literature, mainly case studies, present the performance of specific platforms in relation to the uses, but it is difficult to evaluate the performance goals which should be met.

In order to gather a better understanding of the needs of the market and emerging opportunities, experts across various stakeholders were interviewed. From a product development point of view, understanding your users and their needs is a crucial factor in product success and the interviews were intended for gathering empathy and defining goals and objectives. Since most of the needs in the marine sciences are currently being fulfilled with existing technologies with a high emphasis on cost effectiveness in relation to performance, one of the main goals was to seek to understand these methods and their limitations, in order to set goals for intended uses and discover suitable niches for autonomous surface vehicles. These goals were achieved with various levels of success. There is definitely a high incentive for the development of autonomous platforms and the industry is racing to develop and realize the required technical solutions.

5.1 *Suggestions for different design directions*

Here four different concepts with divergent design directions are proposed. These suggestions are based on the research in this thesis and aim to capture different niches with the goal of having high performance in a cost-effective way. A 'does it all' design is inevitably going to include redundancy for some of the intended use cases and this in turn is going to drive up the costs of the units, which will have to be pushed onto the clients for a viable business case. This will make it difficult to achieve one of the main objectives of the use of ASVs for marine sciences, which is improving on the current methods both in terms of performance and cost. Researchers for scientific purposes are burdened with the never-ending search for funding and although understanding of the marine environment can and likely will reduce costs across different sectors in the long run with better forecasting models leading to better risk assessments and consequently better preparedness for facing problems and legislative efforts. However, acquiring funding for these goals is still a difficult task. In comparison, military applications that have a larger incentive for performance over costs can utilize higher performing technologies without being burdened with cost effectiveness when compared to scientific research. Since the goal of this thesis is to identify opportunities for wind propelled autonomous surface vehicles, the reasoning for wind propulsion is included and discussed in the four concepts.

'The lean supervisor'

This concept is intended for support activities for other instruments by providing them with connectivity. The use cases include improved navigation and communication for UUVs and data retrieval and duty cycle changes for moored and underwater equipment. The design could be simplified to drive down unit costs with material choices and reduced size. This concept is similar to the 3.5 AutoNaut Communications Hub USV launched in 2019, as discussed in the benchmarking section. Similarities to the SailBuoy exist as well with the design calling for a vehicle on the smaller side of available platforms to reduce costs of the unit. However, as the sail buoy has very small propulsion speeds due to the hull size and further effected by wind speed variations, the speed requirements of the marker should be further explored. Researchers and governmental entities have high concerns for the suitability of the use of an ASVs for each measured parameter and require assurances of performance [44][56]. This hinders development time to market and further increases development costs. This concept where the main tool would be an acoustic modem for underwater communications to and from other equipment is be the main design requirement before adding other parameters, would be one way to reach the market with lower development costs. A business case could be to offer access to the platform via missions and leasing acoustic modems for the users of moored installations to meet their needs for systems checks and data download from these installations [44][55]. For moored installations with surface expressions, value could be created from the ability to retrieve data without the use of expensive satellite communications. Additionally, changes to duty cycles could be provided for non-connected installations to better capture expected events, such as rainfall.

'Vertical interest'

As the name suggests, this concept is intended for the capability to observe the subsurface levels of the oceans. The high need for better coverage of CTD-parameters in the Baltic region came up in all three interviews with biological and physiochemical interests with the Finnish interviewees [41][44][56]. This was compounded with the high cost of manned missions and the low suitability of existing unmanned technologies. The Baltic Ocean is a shallow and highly trafficked ocean. Gliders require oversight and the shallowness of the Baltic reduces their efficiency, since more power is needed for the increased up-down-cycles, on which their operation is based. Argo floats have concerns with collisions with other traffic and require manned deployment and retrieval. The Baltic has strong physical boundary surfaces (thermocline and halocline) and further research capability is desired to better reach and quantify these phenomena [56]. In addition to physical parameters, biological interests also require vertical sampling. The use of passive acoustics with hydrophones is one such application and from expert interviews, especially the thermocline of the Baltic causes issues with acoustic measurements and for example the over 80 meter range of the Baltic remains largely un-defined for the presence of the harbor porpoise. Further biological interests include the characterization of vertical plankton distribution and algae concentrations. Since towing applications for hydrophones and lowering profiling units to high depths puts a strain on the platform, the main design consideration for this concept would be to analyze their impact on the mobility of the platform and vessel requirements to complete a vertical sampling cycle. As to the question of how far down a winch should be able to lowered, no clear answer exists, further the better. Further research should then be conducted to define the physical strain of 50, 100 and +200 meter ranges on the platform and the vehicle should be sized as to perform accordingly. Of the four concepts presented in this section this 'vertical interest' concept is the most general use concept for sampling purposes with high suitability for modular use across different parameters.

‘The driver’

This is the largest concept proposed here, with the general idea of utilizing an ASV for launch, maintenance and recovery of other marine instruments such as Argo floats and UUVs. If the recovery of the instruments is desired, the development of this concept is arguably the most challenging one of the concepts presented here. Since the development of a platform that could recover an UUVs or other equipment is considerably more challenging than a vehicle with only launch capability, the first design could simply handle launching of Argo floats or gliders that would be recovered with manned missions. This capability would partially address the high costs of manned missions. However, the deployment of these instruments can already be relatively low cost with a small boat and a few people. Therefore, for a once-off launch of a piece of equipment, wind propulsion might not be the best propulsion design, as the ASV could simply return back to shore after the deployment and replenish its energy source for propulsion. Thus, for wind propulsion to be a viable option here, it could be used for increasing the persistence of the combined system of a surface vehicle and an unmanned underwater vehicle. The UUVs would first be launched and supported during its mission. While that is going on, wind propulsion would be utilized to conserve energy for station keeping for the surface vehicle and additionally batteries would be recharged by means of solar power and wind generators. After the UUVs mission, it would be recovered and charged onboard the surface vehicle. During this the ASV would sail to the next deployment location with low power consumption by sailing and the cycle would then repeat. From reviewing technical presentations from the 2018 Oceanography international conference, other researchers and industry representatives also seem keen on developing similar platforms for launch and recovery of UUVs and various examples exist in different stages of development [33].

‘The lingerer’

This design direction is intended as an alternative to moored installations, such as wave buoys. With the high cost of launch and recovery of bottom-mounted equipment, an ASV could be used instead. However, the ability to maintain position for long periods of time sets some special design considerations. Particularly, based on interviews and the designs of wave buoys, the ability to produce reliable data for wave monitoring applications calls for a circular design [44]. A circular ASV is likely not the best design as the vehicle still requires the ability to sail itself to the location. A compromise where both requirements are met with high enough performance is the main design requirement for this concept and is therefore as its own concept. In addition, the persistence of the vehicle has to be high and harvesting available environmental energy for movement is a good method for achieving this goal. Therefore, wind or wave power propulsion seems to be the best solutions for achieving this goal. Other intended uses in addition to wave monitoring for this concept would include marine weather monitoring that should be done from an elevated position from the surface of the water. This requirement came up in the ‘expert in environmental monitoring’ interview and standards exist for the elevation but were not further researched for this thesis [44]. Another notable application would be current monitoring, likely with ADCP technology. With added sensors, power requirements increase and this concept would also require the ability to either long lasting power sources or the ability to recharge over time or preferably both.

Further discussion on the proposed concepts

The needs and requirements for modularity for sensor configurations were discovered during the benchmarking and interviews and remain an important design requirement for the concepts presented above. Whichever the desired design direction, the ability to increase and re-configure the sensors should be kept in mind during the design process. Even though wind is the desired propulsion method in the ÅSR-project, it has been planned that an additional motor and propelled would be added to the platform to improve the maneuverability of the vessel. One of the motivations for this would be better handling closer to shore, where agility is an important consideration. The use of ASVs close to shores has not really been done yet and would also be a suitable design direction. With wind propulsion designs based sailboat designs with a keel, the issue of high draft compared to other vessel designs becomes an issue. One design to reduce the draft would be the use of multi hull designs, where the momentum of the sails countered with the buoyancy of the hulls. For example for a benthic vegetative research with a 'drop video method' described in the Husö interview a multihull vessel with a propeller could be utilized. As the vessel nears the shore a wingsail could fold down as with the Submaran's design to reduce the wind's effect on the craft and video runs would then be conducted with propeller propulsion before hoisting the wingsail up to sail to the next location. Again, this is speculative, but the strengths of improved control from propeller propulsion should not be over looked. The implementation for passive acoustics could be done with all of the concepts. In the interview with Dr. Klinck one of the more notable uses was station keeping for a day or more while hanging a deployed hydrophone under the vessel [55]. Similarly, small arrays for gliders were mentioned. As the arrays might be tool complex for use with gliders, they could be utilized with small ASVs for a better coverage.

5.2 *Reflection on the methods and results*

In this thesis, interviews with experts from various fields were extremely valuable, as they provided insights into their fields with up to date information on current methods and issues faced in their fields. In comparison to literature research, interviews were a suitable method to assess design directions and gather feedback on ideas generated during the work. The project had a small network of partners from which knowledge of needs and requirements could be gathered. This method of 'mining your sources' was an easily attainable way to gather valuable feedback that was previously not done. Further interviews were also attained by requesting interviews for the thesis from outside contacts. During the ÅSR project, detailed analysis for suitable applications had been postponed partially due to lack of expertise in the desired fields. This was a considerable challenge in this thesis process, since the author came from outside of the fields into which development of commercially viable concepts was desired. Further issues were created from the scope of the thesis, which relied heavily on input from outside sources.

During the interviews, attempts were made into gathering input for the more latent needs in order to gather puzzle pieces for improved future product satisfaction beyond the must have needs required for satisfactory performance. However, without a fixed product design these efforts during interviews mostly ineffective, due to their speculative nature and putting the interviewees on the spot. Most of the answers these questions were of little value and therefore are mostly missing from the interview notes. In anticipation of this issue from previous product development experience, efforts were made to include generative group sessions to the design process in the form of an ideation workshop for the desired modularity concept. As method for identifying latent needs, the workshop seemed suitable, with promising results. However, despite efforts, actual representatives of the desired user-groups could not be attained for the workshop and therefore the results were largely inconclusive. In comparison, the ideation methods presented in the beginning of the opportunity identification, although highly undefined, were an efficient tool in attempts of knowledge transfer for ideas from the interns that were leaving the project.

The design direction of marine research applications was decided on partially due to the requirement for valuable input from outside sources. Researchers from marine sciences were considered to be more likely and willing to provide valuable input in terms of technological requirements and costs of current methods when compared to industrial fields, such as offshore construction and offshore energy, where technologies and costs are more confidential. This decision was compounded with the lack of connections to the commercial fields. Since the need to improve on current methods in terms of performance and costs were of high priority for valuable opportunity identification, a more in-depth knowledge of the prevalent technologies was crucial. Therefore, much of the work in this thesis shifted into understanding the current methods and sensing niches where ASVs could be utilized in a cost-effective way. Furthermore, as the topic of costs and funding in marine research is surrounded in ambiguity, the goal of improving on the prevalent methods becomes more difficult. In hindsight, in order to gain more valuable findings, a more specific use case in the field of marine research should have been chosen when choosing the design direction and it should have also been done earlier on in the process. However, as the research into sensing different opportunities in more detail had been put off in the ÅSR project, this thesis has a place in better understanding of the variables that need to be addressed in order to rationalize and choose more specific product- and service specifications.

5.3 *Suggestions for future work*

For future work a more detailed design direction should be chosen based on the project goals and competences. Further needfinding should then be done for towards the design direction. A suitable method in addition to interviews, would be generative sessions with users and experts relating to the intended use.

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