System of platform-centric warfare

Therese Tärnholm[1,2] and Hans Liwång[1,3]
[1]KTH, Department of Engineering Mechanics
[2]Swedish Armed Forces
[3]Swedish Defence University

Introduction

The research performed by SMaRC will in many ways coincide with development areas of interest to improve the military capabilities at sea such as intelligence gathering and mine hunting. These areas include among others autonomy, sensor development, underwater communication and endurance. To merge the technological research ideas and the needs of future military capability this work will focus on Concept Development of sociotechnical systems where new technology is implemented in an organization like the Swedish Armed Forces.

Aim

The aim for this PhD work is to sharpen the ability within the Swedish Armed Forces in general, the Navy in particular, to make use of present technical development in the underwater arena in concept development and solving present and future operational needs. In this case being the link between existing research and the Swedish Armed Forces when it comes to matters concerning operational needs, concepts and system performance.

Objective

To assist the Navy in looking at concept and capability development with a system-of-platforms mindset instead of a ship centric focus.

Methodology/Technique

To be able to address these questions the work will contain studies in general concept development and how other branches in The Armed Forces work with these matters.

There will also be studies on how other nations handle development and system integration when building new capabilities.

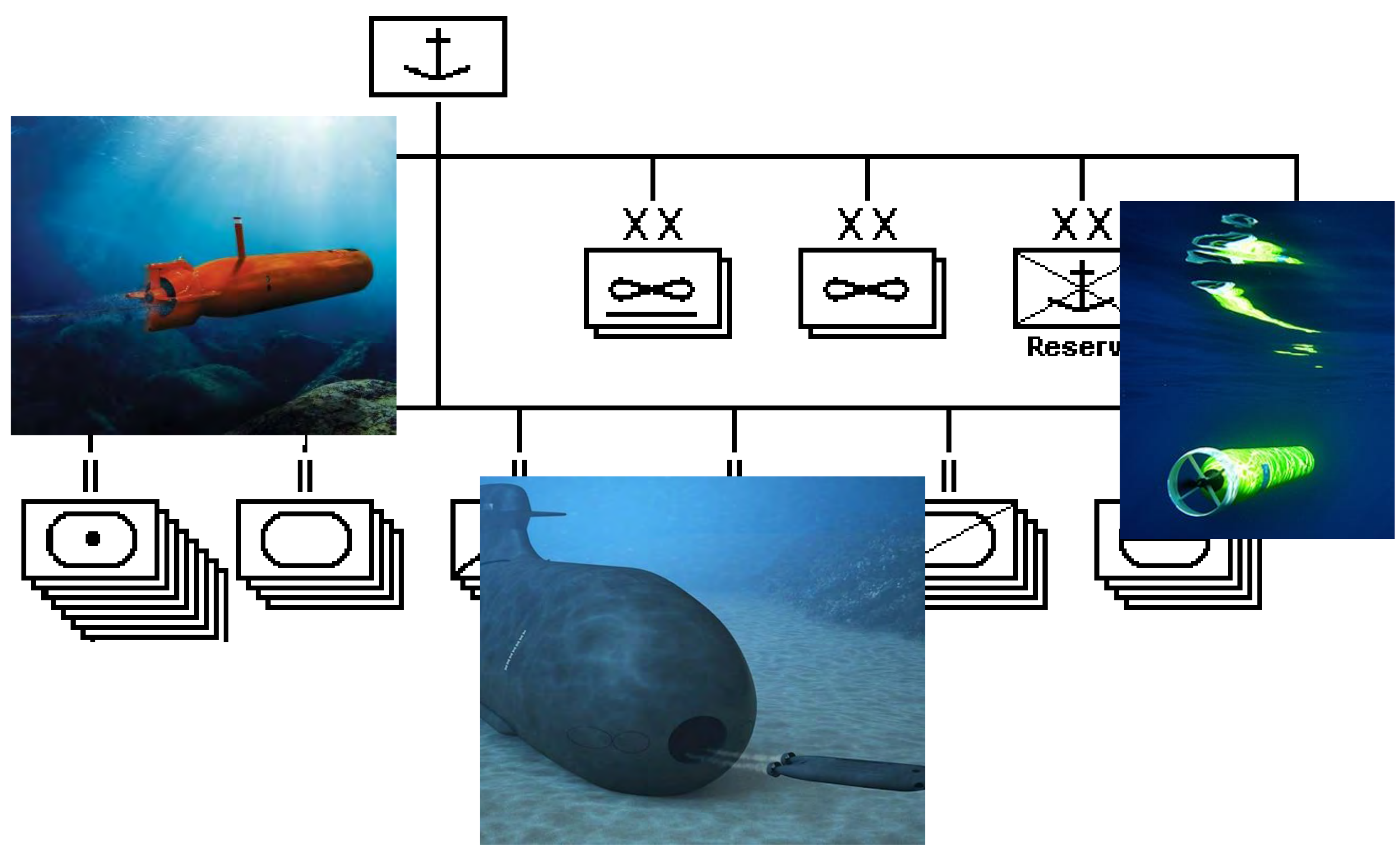
The work in SMaRC and similar research projects will be closely followed both to gain understanding in the technical systems but also to give input about the needs and challenges of the Swedish Armed Forces.

Ongoing work

A comprehensive literature study is performed within the areas of concept development, autonomous vehicles and sociotechnical systems. This work will be able to deliver methods to more efficiently describe, develop and implement concepts for future underwater capabilities. This will include:

- Competence in the methods needed to contribute to the Armed Forces research and development
- Competence in autonomous naval systems for future development within the Armed Forces
- To more efficiently make use of research and development to suit the needs of the Armed Forces

This will help the Navy in looking at concept and capability development with a system-of-platforms mindset instead of a ship centric focus.



Outlook

- Concept development in the process of building new capabilities and units
- Sociotechnical marine systems
  - Autonomous vehicles
  - Manned platforms
  - Human organizations
- How to implement technical progress into organizations like the Armed Forces

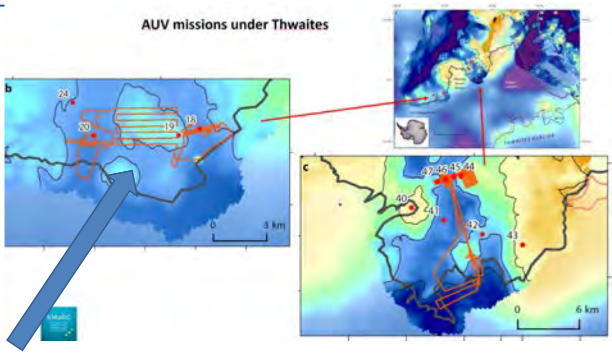
Contact Information :
• Web: https://www.smarc.se
• Email: tejje@kth.se

Pathways of warm water flowing beneath Thwaites ice shelf, West Antarctica

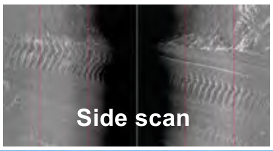
A Wåhlin, J. Andersson, A. Mazur, J. Rolandsson, S. Karam, F. Stedt
University of Gothenburg

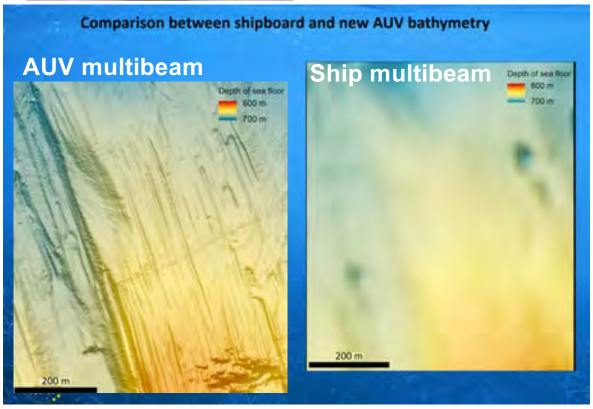
Summary

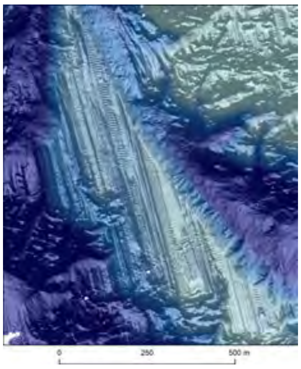
The fate of the West Antarctic Ice Sheet is the largest remaining uncertainty in predicting sea-level rise through the next century, and its most vulnerable and rapidly changing outlet is Thwaites Glacier. Because the seabed slope under the glacier is retrograde (downhill inland), ice discharge from Thwaites Glacier is potentially unstable to melting of the underside of its floating ice shelf and grounding line retreat, both of which can be enhanced by warm ocean water circulating underneath the ice shelf. Recent observations1 show surprising spatial variations in melt rates, indicating significant knowledge gaps in our understanding of the processes at the base of the ice shelf. Here we present the first direct observations of ocean temperature, salinity, and oxygen underneath Thwaites ice shelf collected by an autonomous underwater vehicle. These observations indicate that deep water (> 800 m) underneath the central part of the ice shelf is in connection with Pine Island Bay, which would be a previously unknown westward branch of warm deep water entering the ice shelf cavity. Warm water also enters from the north in two troughs separated by a pinning point. The easternmost of these troughs has southward flow from surface to bottom (0-800 m) towards the ice shelf cavity, while the westernmost (700 m deep) has a northward flow of comparatively fresh and cold water near the surface (0-300 m) and a denser and warmer southward flow near the seabed. The surface outflow is identified as warm deep water found north of Thwaites ice shelf that has been in contact with glacial ice. Spatial gradients of salinity, temperature and oxygen recorded underneath the ice shelf indicate that this is an active region where several water masses meet and mixes.



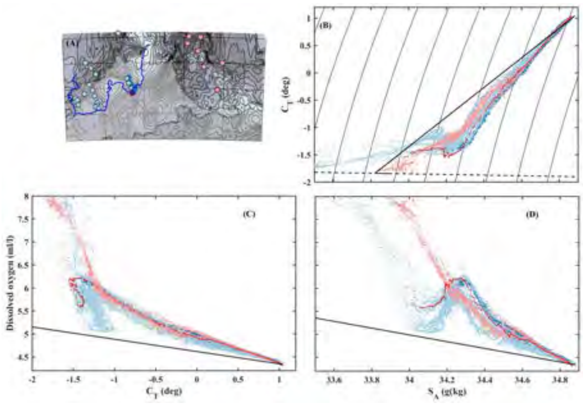
Bathymetry

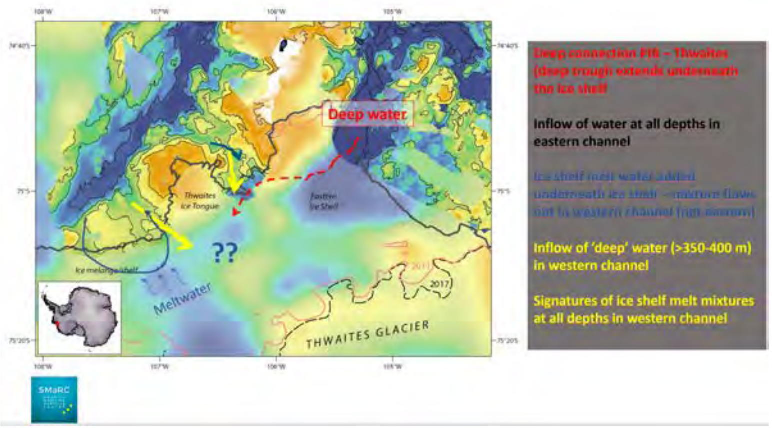






Water masses





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Contact Information :
- Web: https://www.smarc.se
- Email: X@kth.se

Mission Planning and Execution for AUVs

Christopher Sprague, Özer Özkarhaman and Petter Ögren
KTH, Division of Robotics, Perception and Learning

Introduction

The SMaRC AUVs need to be:

- Autonomous,
- Efficient,
- and Safe

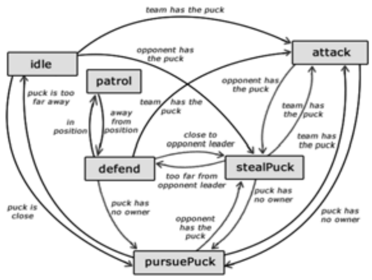
We will use a combination of Behavior Trees and Machine Learning to achieve this

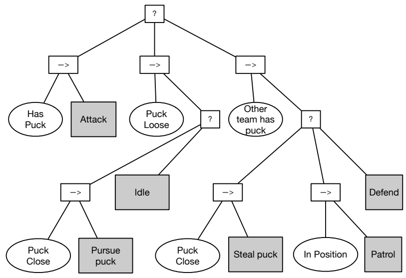
Why Behavior Trees?

BTs are:

- Modular
- Reactive
- Good for human design
- Good for machine design
- Generalize
    - Decision trees
    - Teleo-reactive approach
    - Subsumption architecture
- As expressive as FSMs

BT vs FSMs:
Compare two design for Hockey AI



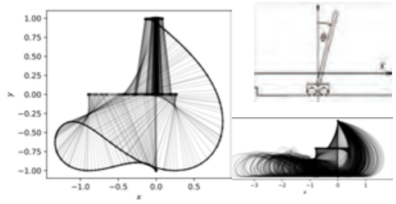


Results

- Collaboration with the National Oceanographic Center (UK) on a new AI architecture for AUVs [1]

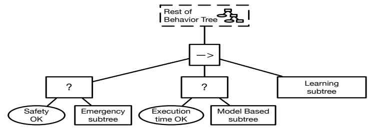
Some of the AUVs operated by NOC

- Using Machine Learning to create low footprint performance optimal controllers that can switch between two given optimality criteria (such as time and energy) online [2].



Learning controllers some large sets of trajectories (a pole-cart example)

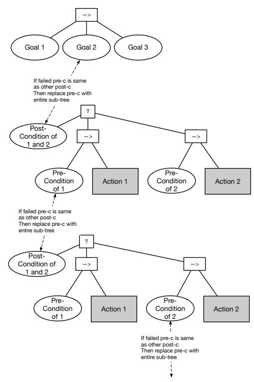
- Investigating a new way to include Learning Controllers into an overall AI design with losing performance guarantees in terms of safety and goal convergence [3]

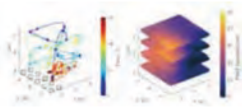


Combining Data driven and Model based approaches

Future Work

- Analyse convergence properties of BTs created using a Backward Chained design principle
- Combine Machine Learning with informative path planning





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Contact Information :
• Web: https://www.smarc.se
• Email: Sprague@kth.se

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Hydrobatics: Efficient and Agile Robots

Sriharsha Bhat[1] and Ivan Stenius[1]
[1]KTH, Department of Engineering Mechanics

Introduction

The term hydrobatics stems from aerobatics and refers to ***agile maneuvering of underwater robots***.
There is a target conflict in Autonomous Underwater Vehicle (AUV) design (*Fig. 1*):

- **Flight style:** underactuated, optimized for efficiency and speed
- **Hover style**: fully-actuated, optimized for maneuverability

Hydrobatic capabilities in underactuated flight style AUVs can make them ***efficient AND agile***, thereby offering disruptive new designs and capabilities

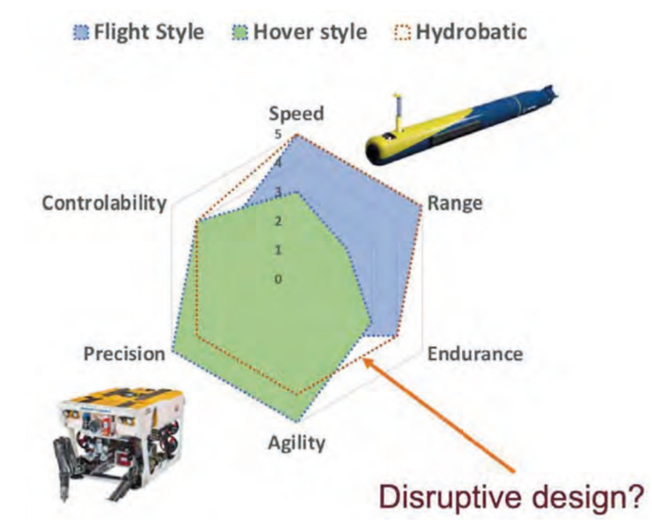

Fig. 1: AUV performance trade-offs [1]

Aim

To push the boundaries of underactuated AUVs and explore hydrobatic capabilities for new use case scenarios (*Fig. 2*).

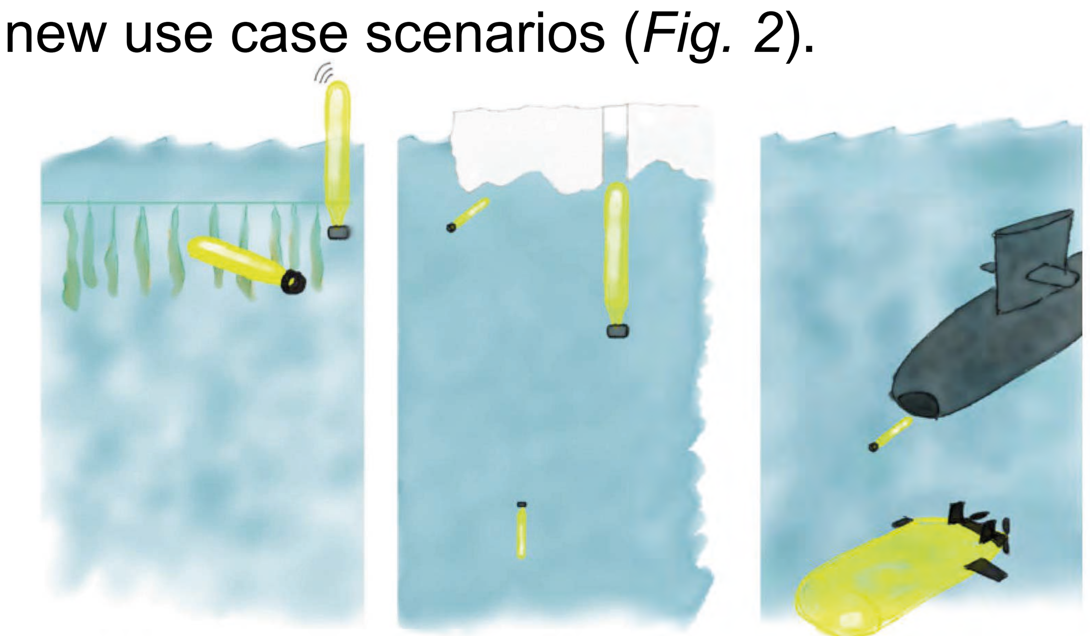

Fig. 2: Impact areas for hydrobatics [1]

Objectives

To address two key challenges-

- **Flight dynamics modelling**
- **Underactuated control**

and demonstrate use cases of hydrobatics [1].

Methodology/Technique

Simulations are tightly coupled with hardware, and model-based methods will be used to demonstrate hydrobatic control strategies in the field (*Fig. 3*).

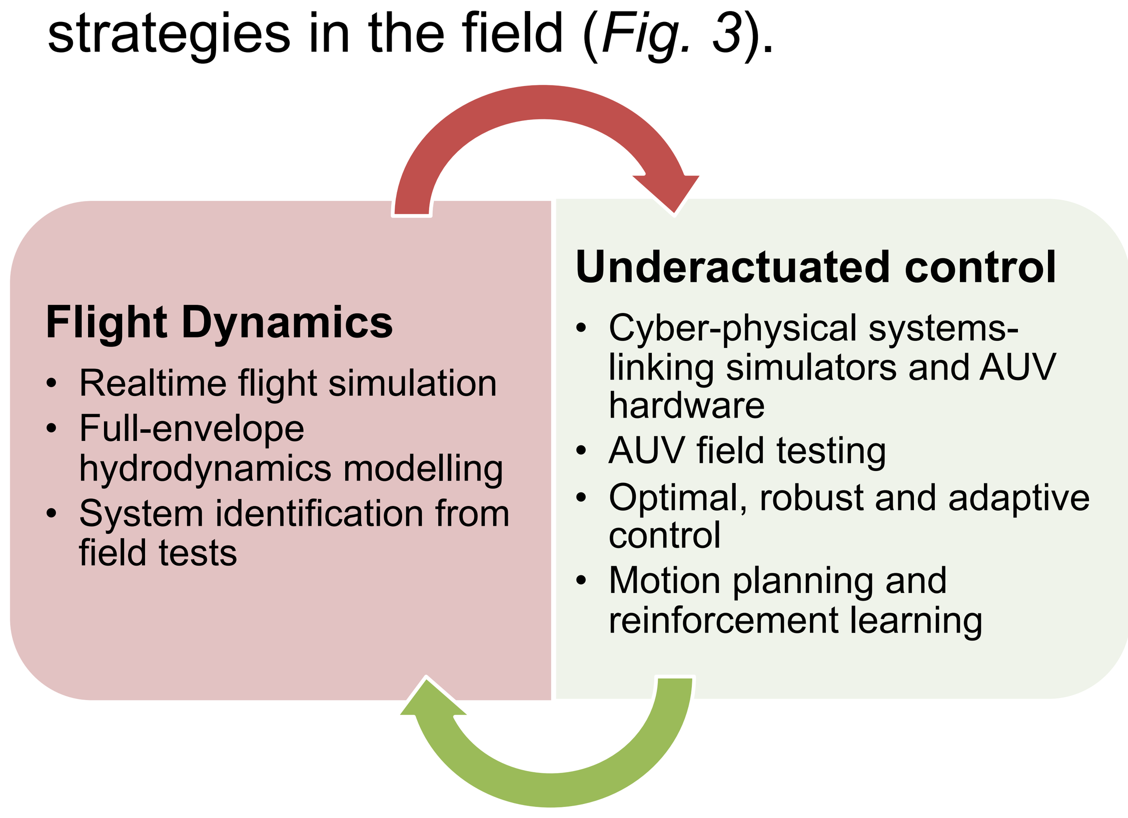

Fig. 3: Methodology coupling modeling and control

Results

1. Real-time flight simulation of hydrobatic AUVs [2]
combining analytical, semi-empirical and computational methods to derive flight dynamics over the full 0-360° AoA envelope (*Fig. 4*).

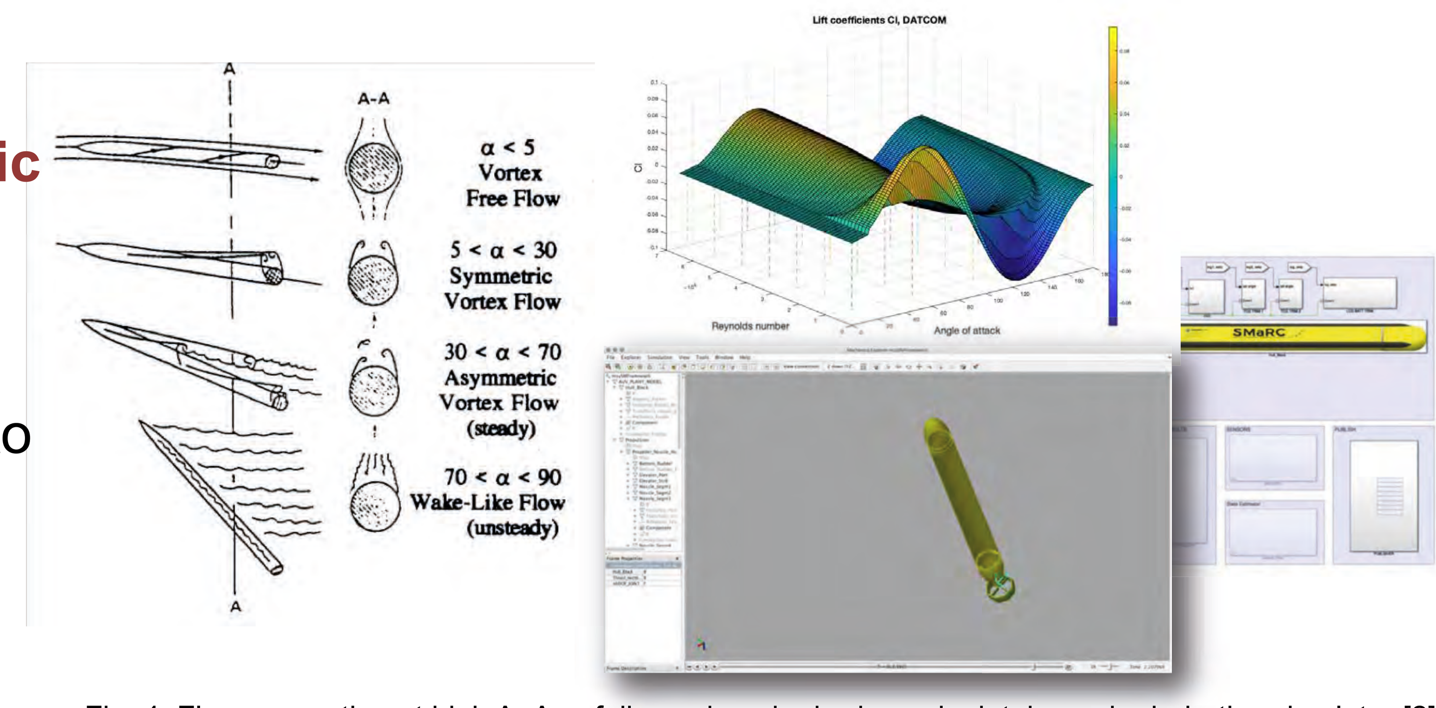

Fig. 4: Flow separation at high AoA, a full envelope hydrodynamic database, hydrobatics simulator [2]

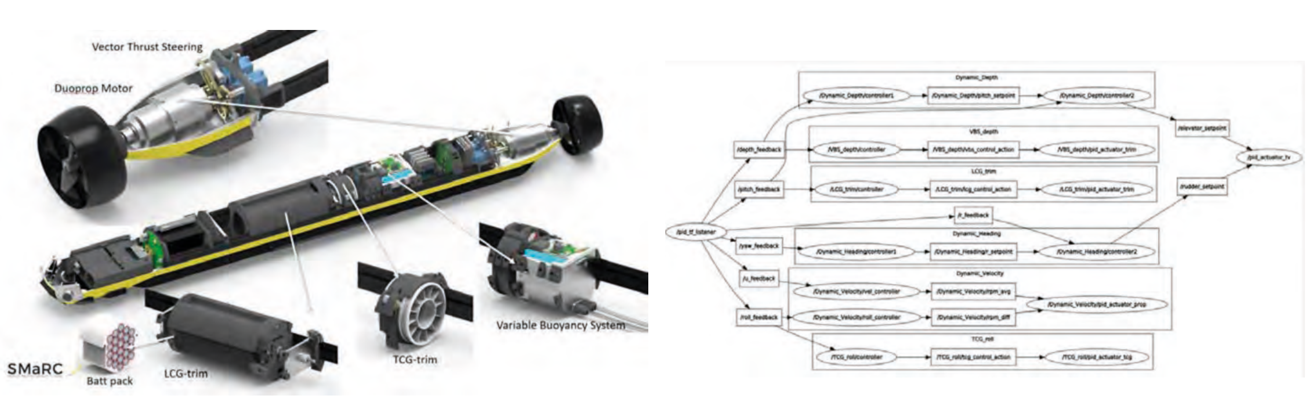

Fig. 5: SAM AUV subsystems and controllers

2. Controllers for the SAM AUV -

- **Trim control**
  - LCG
  - TCG
  - VBS
- **Flight control**
  - Heading control
  - Roll and velocity control
  - Dynamic depth control

3. A cyber-physical system[3]

- Simulators are tightly integrated with hardware through the CAN Bus and ROS (*Fig. 6*).
- Controllers are developed and tuned in Simulink/ Gazebo/ Stonefish.
- These are then deployed on to the SAM AUV.

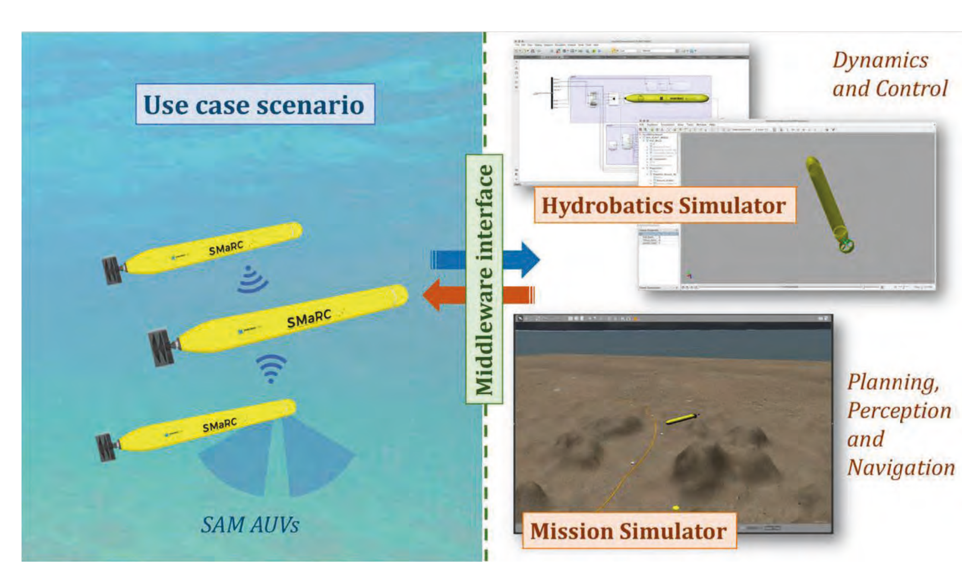

Fig 6: Our cyber-physical system concept [3]

Outlook

A framework has been built with the simulators, robot (*Fig. 7*) and the CPS. The upcoming focus is on developing **optimal and robust control strategies** for real world use cases, e.g.

- Under-ice launch and recovery
- Inspection
- Docking
- Target tracking

Fig 7: The SAM AUV before deployment

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Stockholms Universitet
FOI

Contact Information :
• Web: https://www.smarc.se
• Email: svbhat@kth.se

Classification of Sonar Data

Louise Rixon-Fuchs[1] Andreas Gällström[2]
[1]KTH, Division of Robotics, Perception and Learning
[2]Saab Dynamics

Introduction

Sonar is the preferred choice of sensor for imaging under water due to its long range and robustness to turbidity. Thus sonars are also a typical choice of sensors for Autonomous Underwater Vehicles (AUVs) for tasks such as obstacle avoidance, detection, classification, navigation, map building and Simultaneous Localization and Mapping (SLAM).

Aim

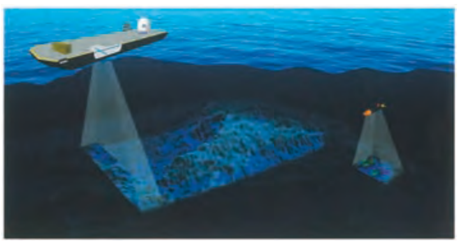
The focus of this project is on enhancing detection and classification for sonar systems. Robust classification of sonar data still remains a problem due to challenges such as view-dependence, nonlinear acoustics, and sensor dependent data. If solved it would enable more autonomy for underwater vehicles providing more reliable information about the surroundings to aid decision making.

Objective

Recent advances in image recognition using deep learning methods have been rapid, however for sonar data these types of methods have not been explored to a great extent. Recent work in this project has been focused object recognition in acoustic images from forward looking sonars (FLS), and on enhancing sonar imaging for Synthetic Aperture Sonar (SAS) by replacing parts of the sonar signal processing chain with methods using Compressive sensing (CS) and Generative Adversarial Networks (GANs).

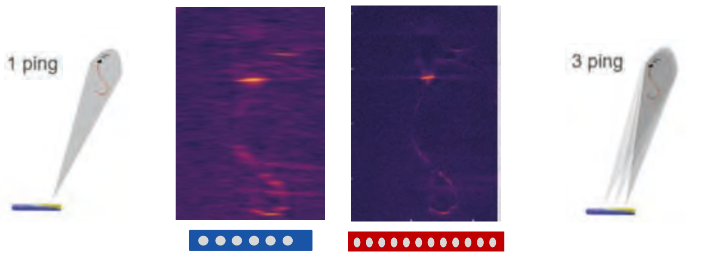
Methodology/Technique

Use deep learning based techniques for enhanced sonar imaging, such as compressive sensing, deep learning based approach (cGAN), seabed classification of SAS images, and multi-view learning for sonar object recognition.

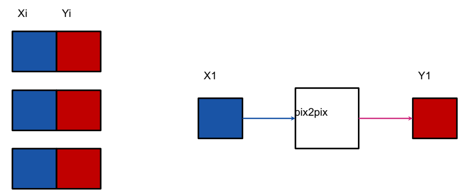


Results

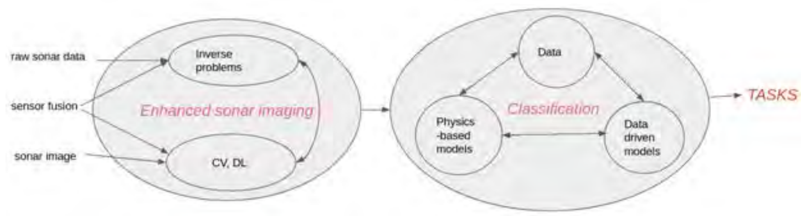
- Conventional way of getting a higher resolution (in SAS, create a longer array)
- Motivation: Can we use recent advances in image-to-image translation to enhance sonar image resolution?



Enchanged image resolution through image-to-image translation: The cGAN is trained to go from the image domain with low resolution (short array) images to high resolution (long array) images.



Enabling autonomy through better classification of sonar data:



Outlook

For the future the plan is to work on image enhancement methods for Synthetic Aperture Sonar (SAS) (including image registration and autofocus), and to work on multiview learning for sonar object recognition for various sonar sensors. We have recently collected a dataset for SMaRC with data from multiple sensors: side-looking sonar, forward looking sonar and multibeam. The aim with this dataset is to create a SMaRC dataset for object recognition, navigation and docking.

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Contact Information :
- Web: https://www.smarc.se
- Email: X@kth.se

Underwater docking

Filip Söderling[1] Roger Berg[1] and Jakob Kuttenkeuler[2]

[1]SAAB Kockums

[2]KTH, Department of Engineering Mechanics Royal Institute of Technology

Introduction

Having the capability to dock an Autonomous Underwater Vehicle (AUV) with a habitat allow users to prolong the vehicle operation time and reduce the need for human interaction. Using habitats for charging and exchange data with the vehicle makes it able to do back-to-back missions without recovery in. Kelp farms is an example of where a stationary habitat could prolong the vehicle time in operation area and make monitoring autonomous. Also within defense and security there is an advantage of using habitats for long term monitoring harbors for example, also docking towards moving targets such as a surface ship or submarine is a possible scenario.

Aim

Demonstrate successful soft docking sequence from AUV without any contact with target, approach the moving target and lock its relative position and establish a logic leash.

Objective

Demonstrating the docking sequence is made possible through design of software enabling and restricting the AUV behaviour in relation to the target, through intelligent path planning, control strategies, positioning methods.

Docking sequence

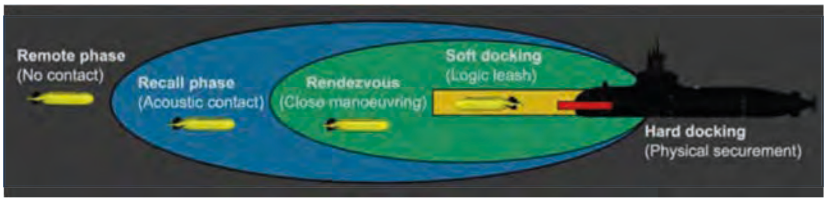


Figure 1. The figure shows a schematic view of a full docking sequence, here towards a moving target in the shape of a submarine

To be able to complete a docking mission the AUV must work through the phases and gradually increase the accuracy in relative positioning. In soft docking the aim is to establish a Logic Leash where the vehicle follows the movement of the target while being in front of it.

Methodology/Technique

Gather real environment data, feed into theory and develop, compare, benchmark algorithms and techniques. Implement suitable software into vehicle and adapt sufficient hardware. Perform real environment demonstrations and create publications of established results.

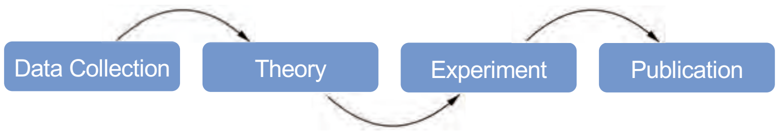


Figure 2. Work flow underwater docking research

Results

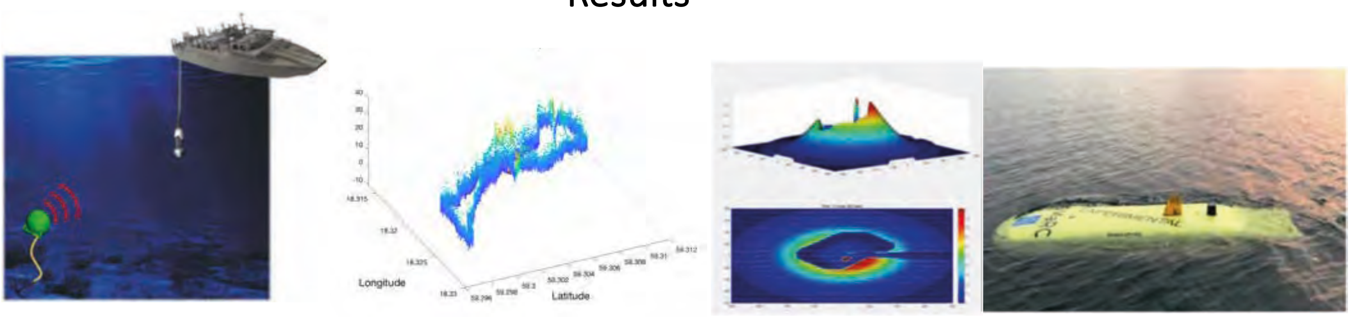


Figure 3. The figures shows the setup of collecting sonar data to be used to configure a sonar model, the collected Sound Pressure Level data, and an example of search algorithm, to be implemented and tested in real environment with the research platforms developed within SMaRC.

Outlook

In June 2020 the ability to search and locate the target using developed sonar model and hardware together with a search algorithm will be demonstrated in real environment. The hardware used will be a sonar developed by KTH in collaboration with Cadson, another SMaRC partner. Figure to the left is an illustration of the vision of using underwater docking within SAAB Kockums.

Contact Information :
- Web: https://www.smarc.se
- Email: filipsod@kth.se

Energy Management Strategies for Fuel Cell/Battery AUVs

Ariel Chiche[1] Clemens Deutsch[2] Göran Lindbergh[1] Ivan Stenius[2]
Jakob Kuttenkeuler[2] and Carina Lagergren[1]
[1]KTH, Department of Chemical Engineering
[2]KTH, Department of Aeronautical and Vehicle Engineering

Introduction

Fuel cells and batteries are electrochemical devices that convert chemical energy in electricity. They are composed of two electrodes (anode and cathode) and one electrolyte. The main difference between battery and fuel cell is that a battery is a closed system with the energy stored in the electrode materials, whereas a fuel cell is open. As long as the fuel cell is fed by reactants, it can produce electricity. **Hybrid fuel cell/battery systems** combine the advantages of fuel cells (high energy content) with the ones of the battery (high power flexibility) to ensure long-range missions for AUVs [1]. Modeling such hybrid systems is a key step in order to build a really energy efficient vehicle [2].

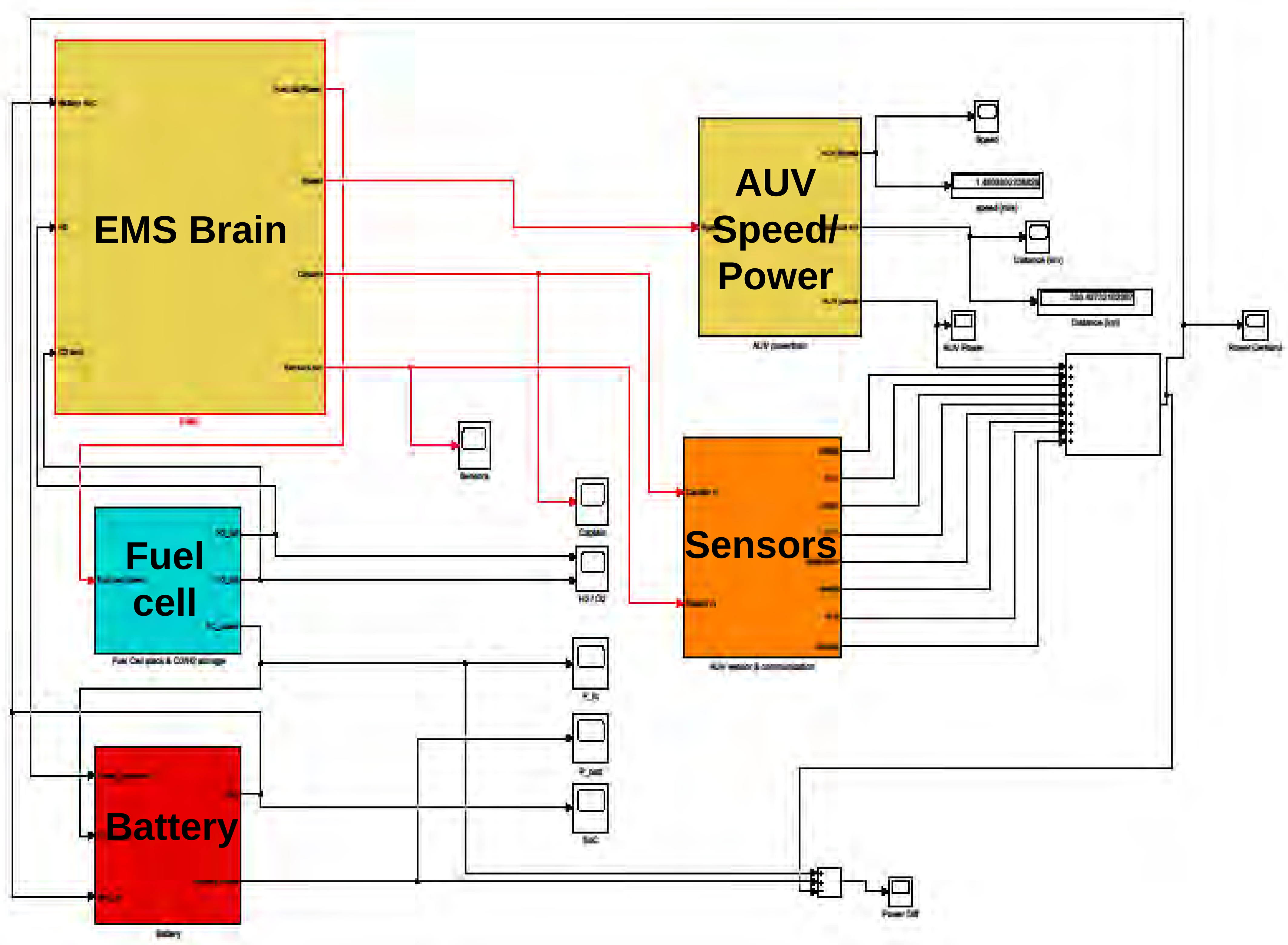
Aims and objectives

A **Simulink** model of a full hybrid fuel cell/battery coupled with an AUV was built in order to test several Energy Management Strategies (EMSs). It is composed of both theoretical and empirical equations.

The model has several goals:

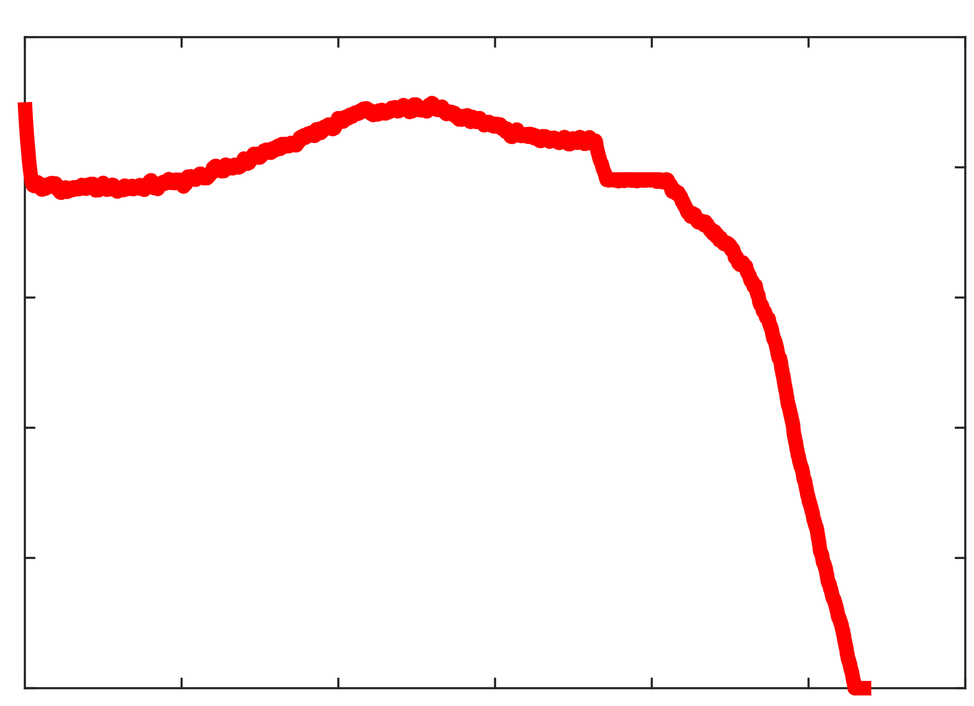
- Be flexible and offer the possibility to change both the AUV and the energy system
- Compare different Energy Management Strategies
- Highlight the capabilities of the AUV
- Predict the behaviour of the AUV during critical missions

Methodology/Technique



The figure shows layout of the built Simulink model with all its components and their interactions.

Results



The figure shows the evolution of the battery State of Charge (SoC) while running a routine mission with a LoLo-like AUV with a fuzzy logic strategy.

Outlook

The built Simulink model is under development but already offers the possibility to implement any AUV with any energy system. The fuzzy logic approach shows promising capabilities for such systems [3]. A first series of tests have been performed confirming this trend.

More strategies will be investigated in the future.

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Contact Information :
- Web: https://www.smarc.se
- Email: chiche@kth.se

Underwater Networks

Elias Strandell Erstorp[1] Peter Sigray[2]
[1]KTH, Department of Engineering Mechanics
[2]FOI, Department of Underwater Research

Introduction

Acoustic underwater sensor networks are subject to low bandwidths, severe channel variability in both space and time, high energy consumption per transmitted amount of information, long propagation delays and multipath interference. Not only would normal terrestrial (radio) network protocols perform badly in this environment but developing underwater network protocols for a general case is difficult, if not impossible. Thus, to develop efficient network protocols for the underwater domain, one needs to consider both the environment and application requirements, resulting in tailored and often cross-layered solutions [1].

Aim

- To develop tailored network protocols for the different SMaRC operational scenarios.
- To investigate the possible benefits of using directive communication and how these can be utilized by network protocols.

Objectives

- Implement a flooding-based routing protocol for a commercial acoustic modem [2].
- Analyse and propose protocol solutions to SMaRC scenarios.
- Measure channel characteristics using a beamforming transmitter and build a model that can be used in simulations of direction-aware network protocols.

Methodology/Technique

- Network protocols are being developed and tested in the UnetStack framework [3]. UnetStack is an agent based software. The stack allows for cross-layer interaction, dissimilar to classical networks, to give network researchers a high degree of freedom and decrease overhead.
- A transducer array (Fig 4 and 5) will be used to perform channel measurements.
- Direction-aware network protocols will be simulated in UnetStack.

Results

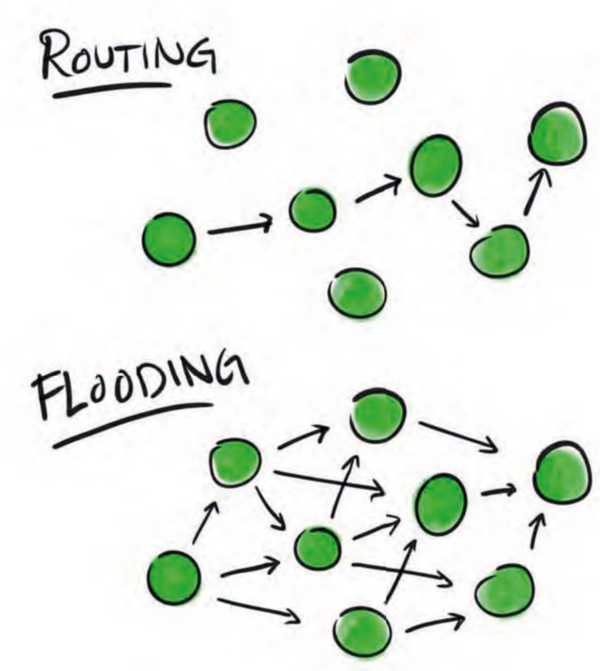

Fig 1. Routing versus flooding. We want to develop a hybrid.

Fig 3. Protocols are tested on commercial modems.

Fig 4. Design of a beamforming array.

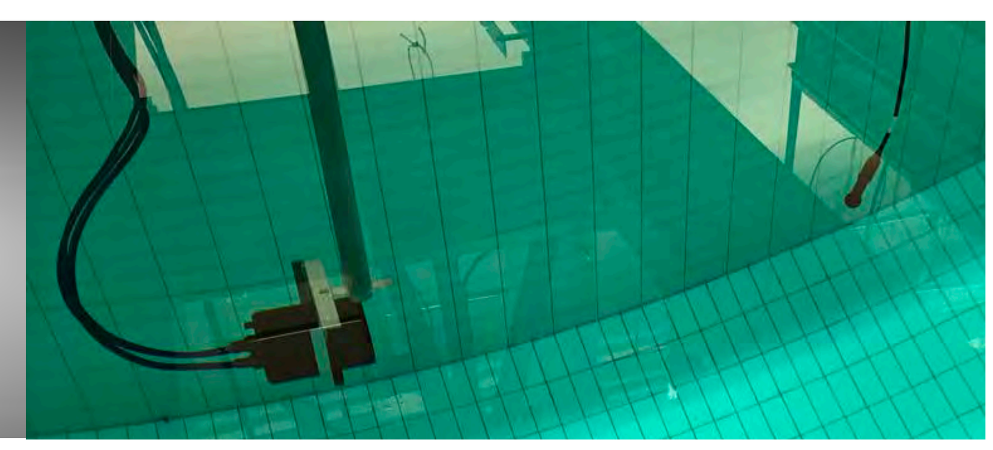

Fig 5. Directivity pattern measurements of the transducer array.

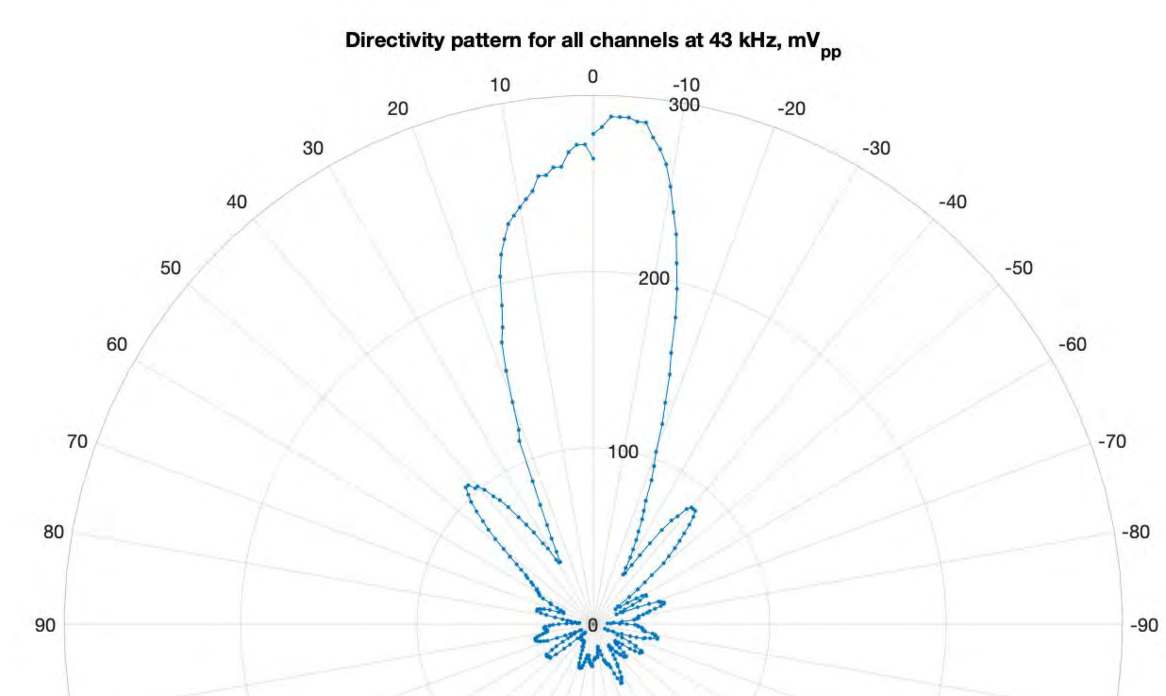

Fig 6. Measured directivity pattern.

Outlook

Implementation of the flooding protocol should be finished and tested by March 2020. Routing features will be added to the protocol and tested during summer.

In a master thesis project, the beamforming properties of the sonar array is investigated. Channel measurements will be performed later in 2020.

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Swedish Foundation for Strategic Research
Göteborgs Universitet

Contact Information :
- Web: https://www.smarc.se
- Email: eliasse@kth.se

System Performance Optimization

Clemens Deutsch and Jakob Kuttenkeuler
KTH, Department of Engineering Mechanics

Introduction

The **performance** of underwater vehicles is described as the quality of completion of its assigned task. Performance is strictly task-dependent and can be evaluated e.g. in terms of energy efficiency, manoeuvrability, reliability, or payload capacity. Increased vehicle performance allows end-users to access yet inaccessible environments, such as subglacial basins, effectively reduce costs (ship time) and collect more and better data.

Fig. 1 An underwater glider developed at the KTH Centre for Naval Architecture

Aim

Improve the performance of underwater vehicles through system optimization, enabling missions with **extended range and endurance**.

Objective

Performance is improved through **clever design** of hard- and software and enhanced by **artificial intelligence** (AI) and sophisticated **control algorithms** for navigation and path planning. This includes

- Hydrodynamic design
- Propulsion methods and propulsors
- Energy systems
- Optimal control strategies

Methodology

Holistic study of vehicle-related performance factors:

- Flight mechanics & hydromechanics
- Velocity effects & scale factors
- Manoeuvring & control strategies
- Payload usage & other operational parameters

The research is conducted on a **simulation-based** approach with substantial **experimental verification** using the SMaRC demonstrators LoLo and SAM as well as the AUV Ran.

The **Interdisciplinarity** emphasizes the importance of collaboration with other researchers from within SMaRC.

Results

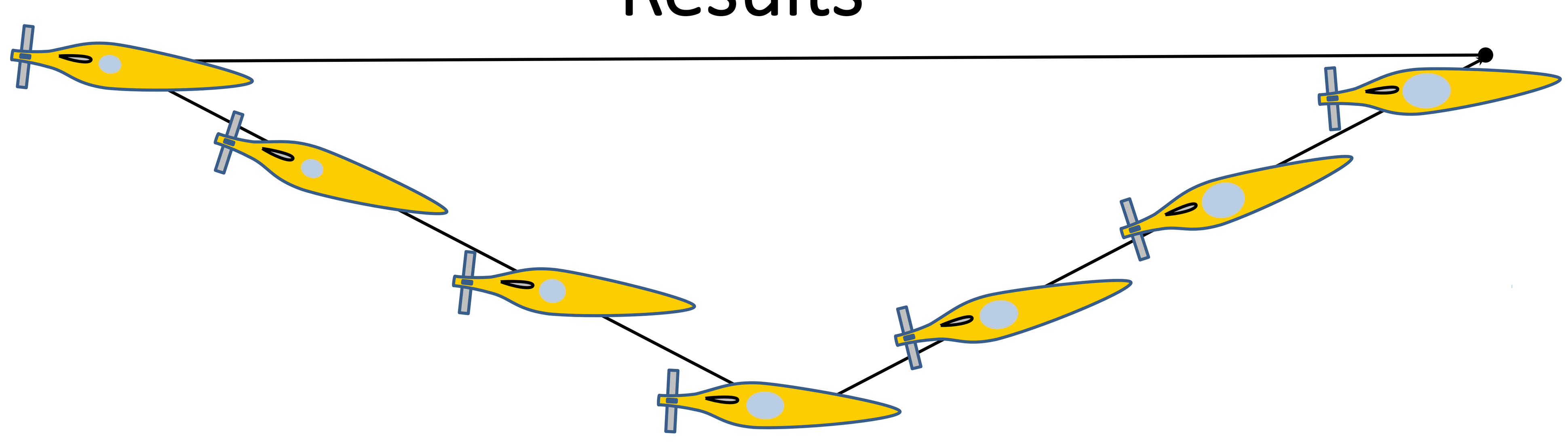

Fig. 2 A typical underwater glide cycle. The glider uses a buoyancy system to change its buoyancy and propel forward through the water column in a zigzag pattern.

Recent research [1] has provided a **glide metric** (C_{GL}) for the evaluation of transit efficiency of underwater gliders based on hydrodynamic coefficients for lift (C_L) and drag (C_D)

$$C_{GL} = \frac{C_D\left(C_D^2+C_L^2\right)^{3/2}}{2C_L^3}.$$

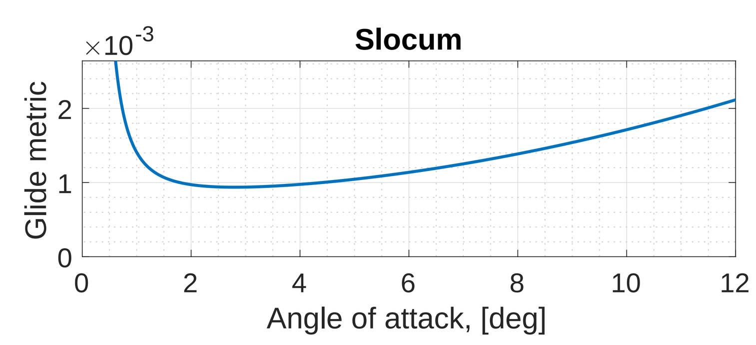

Fig. 3 Slocum's glide metric as a function of the angle of attack. No Reynold's number dependency.

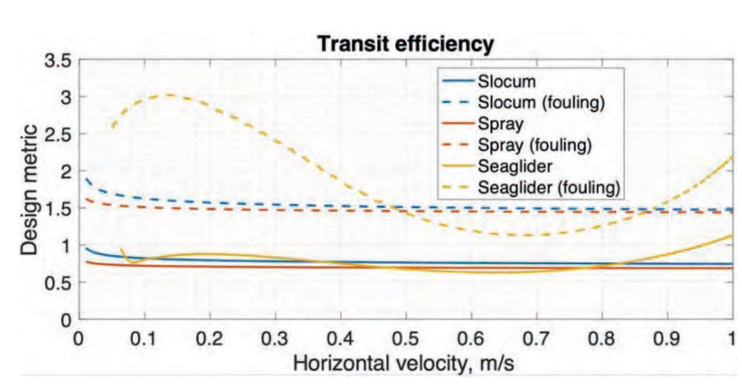

Fig. 4 The transit efficiency of the legacy gliders compared to propeller-modified versions, expressed in terms of a design metric for ideal and biofouling conditions.

Numerical [2] and experimental data [3] of the underwater gliders *Slocum, Spray* and *Seaglider* has been used to analyse their transit performance, with the results shown in Fig. 3 and 4. Results show that under ideal conditions, gliding is the more efficient means of locomotion. Already medium levels of biofouling, however, can inflight heavy penalties on the gliders' efficiency, rendering them inferior to propeller-driven vehicles.

Outlook

Following the holistic approach of vehicle optimization, vehicle performance will further be improved by research on

- **Energy Management Strategies** for Fuel Cell-Hybrid Underwater Vehicles
- **Optimal Control** Applied to Underwater Vehicles
- **System Identification** Using Reinforcement Learning

References

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Stockholms Universitet
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Contact Information :
• Web: https://www.smarc.se
• Email: clemensd@kth.se

Simultaneous Localization and Mapping with AUVs

Ignacio Torroba, John Folkesson

Division of Robotics, Perception and Learning, KTH

Introduction

Simultaneous Localization and Mapping (SLAM) is a set of techniques aimed to enable autonomous platforms to build maps of unknown terrain while estimating the vehicle trajectory. Underwater SLAM is particularly challenging due to the limited sensing and communication capabilities of an AUV, together with the changing dynamics and lack of landmarks in submarine environments.

Aim

Enable AUVs to explore and map bast regions of seabed accurately on long-term missions. For this, our SLAM solutions must provide an accurate vehicle pose estimate, which will be used by the AUV navigation system.

Objectives

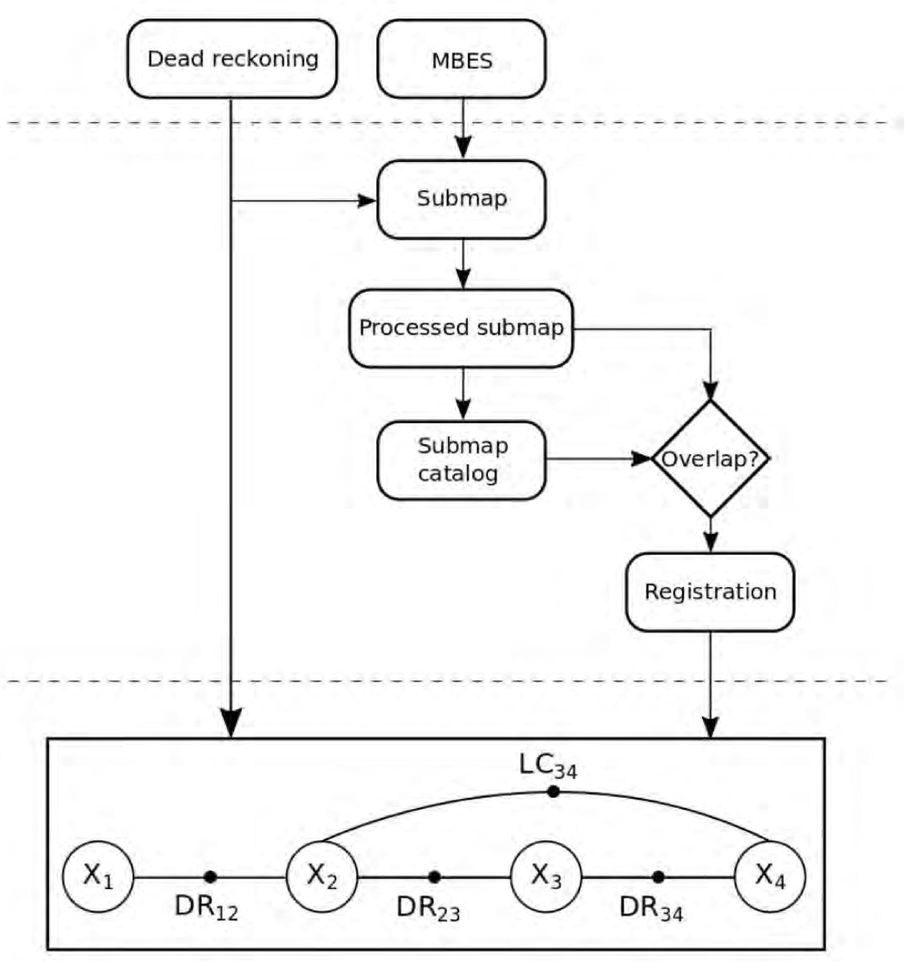
- MBES-based Bathymetric SLAM for long-range surveys [1][2].
- Loop closure detection MBES, SSS and/or biochemical sensors [3].
- Active SLAM: combined SLAM and mission planning to achieve intelligent exploration.

Methodology

Given the raw multibeam and the dead reckoning estimate from an AUV survey:

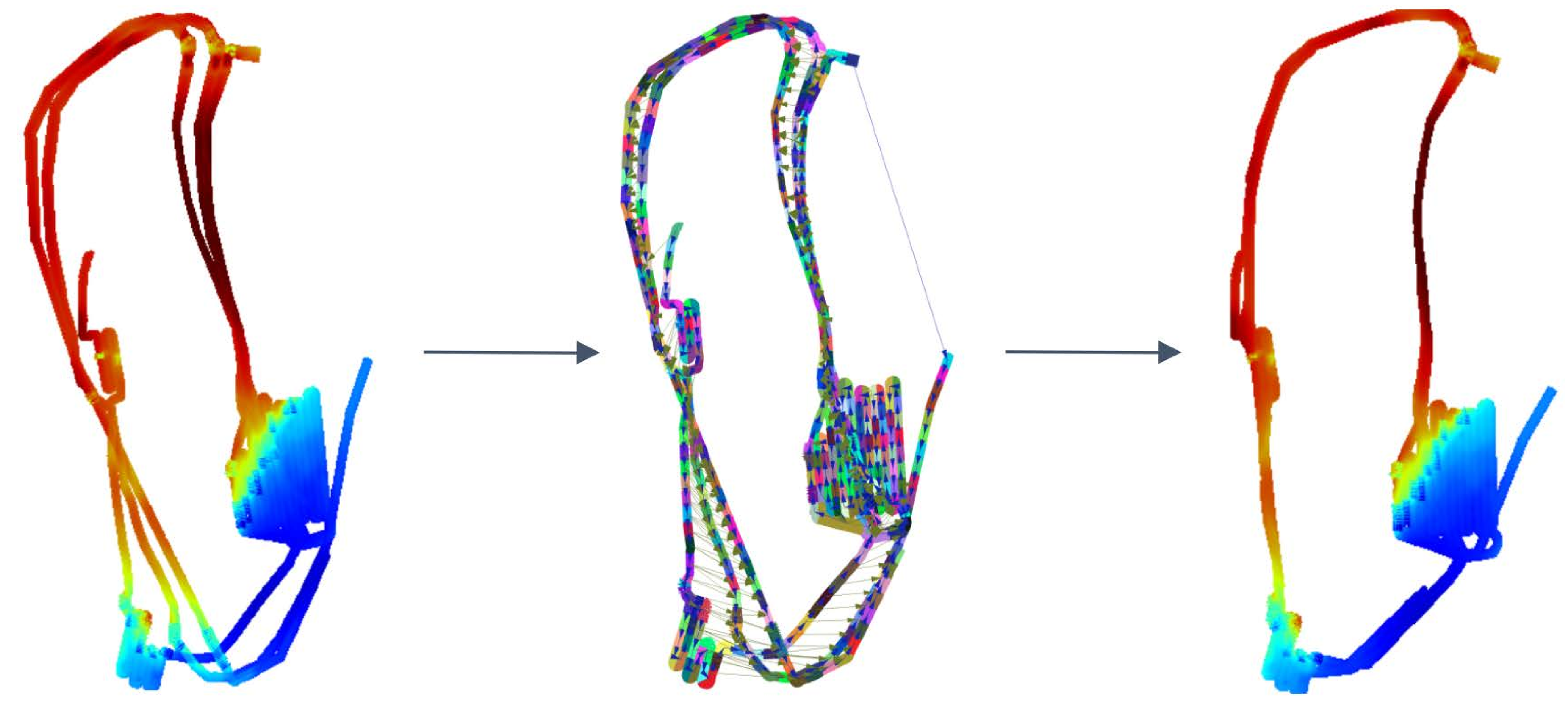
1) Correct the vehicle pose maximizing the consistency of the current bathymetric patch.

2) Global optimization over the entire map and trajectory.



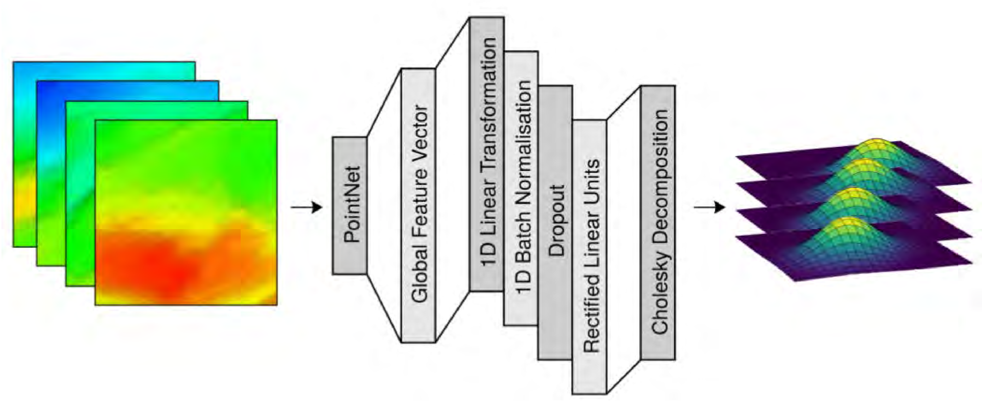
Results

1. SLAM framework for accurate bathymetric surveying [1]

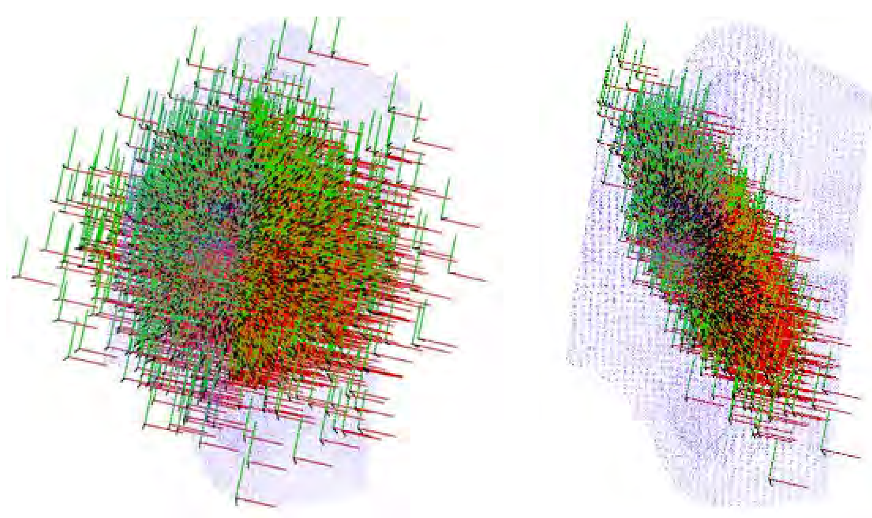


From left to right: bathymetric map from noisy dead reckoning, visualization of our method applied and corrected output from the SLAM optimization.

2. PointNetKL: inference of the noise model of bathymetric GICP registration [2]



PointNetKL network architecture with input and output visualization



2D prior and posterior covariance of a bathymetric submap.

The shape and scale of these covariances model the underlying bathymetry such that it can used in the SLAM optimization from [1].

Outlook

i) Improved vehicle trajectory estimate and map reconstruction from AUV surveys
ii) Biochemical sensors can be potentially useful for loop closure detection.
iii) Current work on active SLAM and integration of SSS on the framework.

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Contact Information :
• Web: https://www.smarc.se
• Email: torroba@kth.se

Raman sensor for organic pollutants in low concentrations

Katarina Abrahamsson[1] and Adela Dumitrascu[2] [1]University of Gothenburg, Department of Marine Sciences
[2]MMTAB

GÖTEBORGS UNIVERSITET

SMaRC SWEDISH MARITIME ROBOTICS CENTRE

Introduction

Physical sensors exist for measurements of ocean temperature, pressure and salinity, and are rapidly reaching a mature stage of development. In contrast, biogeochemical sensors are in their infancy and are dominated by large macro (~0.5m^3), expensive one-off devices requiring expert operation (and intervention). Many of the parameters of interest are present in very small concentrations. These low levels must not only be detected, but quantified with a high degree of confidence. Sensing technologies must at least have limits of detection that are applicable to the marine environment, and resolution of less than 2% of the range of concentrations present. Preferably sensors for a given parameter should be able to operate over the range of concentrations present in all target environments. Many published and commercialized techniques are orders of magnitude short of this target.

Aim

The project include the development of a sensor system based on a modular design utilising fibre optic interconnections, where the parts can be exchanged and modified in the field. The development includes an adaptation to a high level of automation in order to compensate for variations due to environmental factors, such as temperature and pressure, acting on the instrument

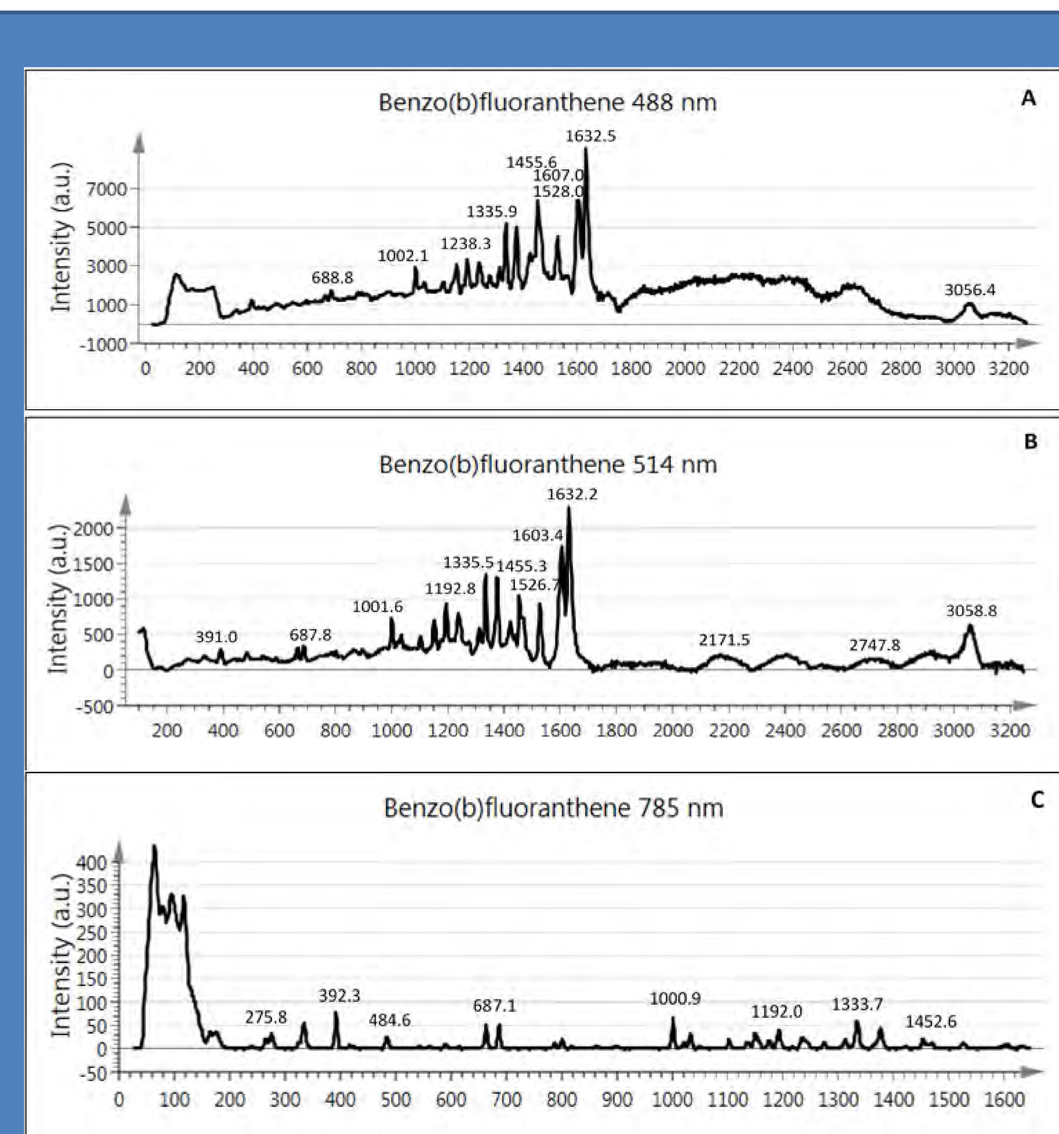
Objective

The project include the development of a sensor system based on a modular design utilising fibre optic interconnections, where the parts can be exchanged and modified in the field. The development includes an adaptation to a high level of automation in order to compensate for variations due to environmental factors. The sensor technology will at a start focus on polycyclic aromatic hydrocarbons (PAH).

Methodology/Technique

The sensor will be based on Raman spectroscopy, which is a technique based on inelastic scattering of molecules. The raman signal is selective, informative and insensitive to water. To reach the target levels we will utilise surface enhancement, which can be achieved through the incorporation of metal structures or particles. The evaluation of the spectra will be performed by multivariate statistical approaches which include filtration, scaling etc. Presently, we are participating in a one year expedition to the Arctic (MOSAiC) where we are measuring organic compounds at low concentrations (www.mosaic-expedition.org)

Results



The figure shows the Raman spectra of one PAH measured with three different Laser wavelengths

Several parameters needs to be optimised whereof the metal used for enhancement in combination with the laser wavelength is the most crucial. We have tested mixtures of 15 PAH in different types of sea water and concentration levels in order to find the best combination. The Figure shows the effect of the illumination source. At higher energy sources the signal intensities are higher. However, in natural samples the risk for interferences by fluorescence increases

Outlook

Our future work will be focused on the evaluation of the information received by the sensor. The challenge is to be able to filter out the relevant signal from interferences in real time. This include a) identifying relevant spectral bands b) minimising background noise c) backgound correction and d) extraction (1). As a start point wavelet transformation will be applied.

References

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Contact Information :
• Web: https://www.smarc.se
• Email: Katarina.Abrahamsson@gu.se

Multi-AUV Mission Planning

Özer Özkahraman, Petter Ögren

KTH, Division of Robotics, Perception and Learning (RPL)

Introduction

One vehicle can only do so much. When the areas that need to be covered are vast or there are spacial and temporal constraints in the mission, one vehicle is simply not enough. In such circumstances, multiple vehicles must be used in order to accomplish the given task. Such tasks include but are not limited to coverage, search, and capture. In our works, we have examined and formulated methods that tackle these problems using multiple affordable underwater vehicles. To that end, we have developed algorithms and processes that can compute the requirements for a given mission and generate the mission plan automatically.

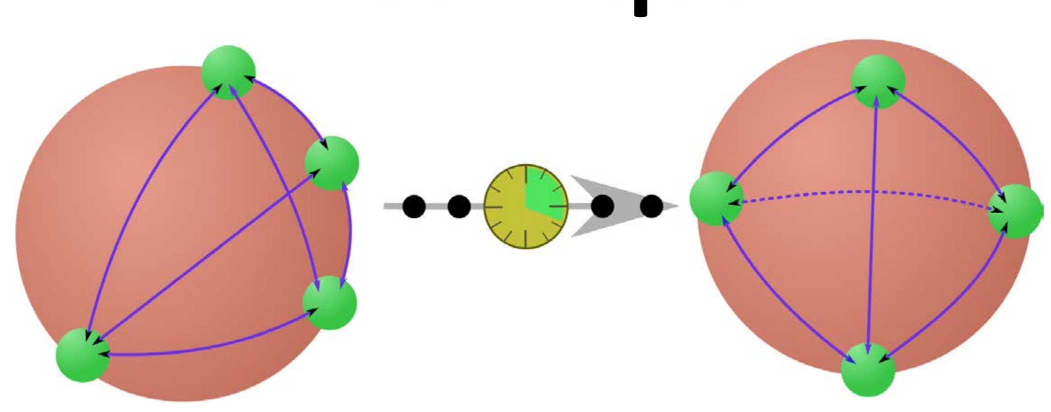
Aim

Our aim is to create algorithms and processes that can generate mission plans for multiple AUVs in order to complete a given task and do so while optimizing some objective.

Objective

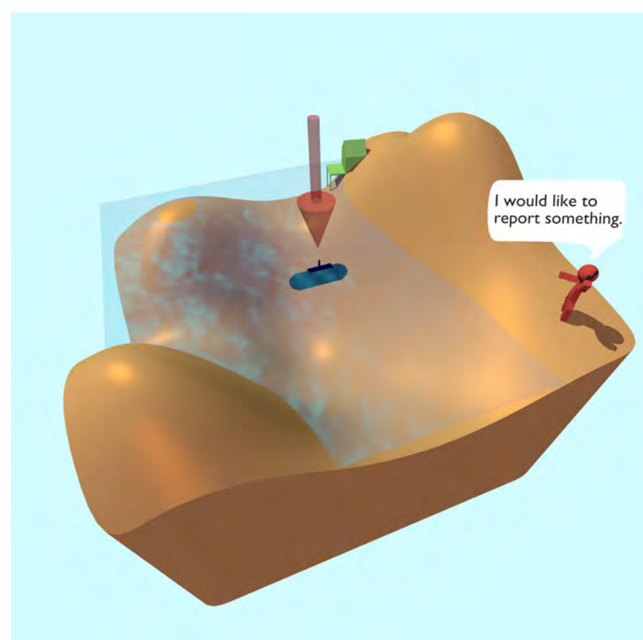
Use fewer vehicles.
Complete the task faster.
Be robust to failures.
Handle uncertainties.
Be understandable.
Cooperate to achieve all of the above.

Technique

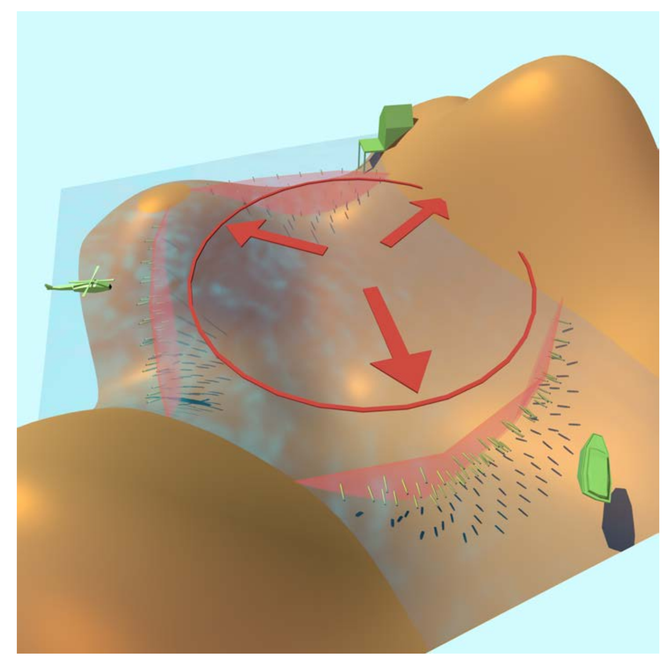


In order to solve the caging problem, we solve the following sub-problems:
- Min-cut Max-flow Problem: Used to partition the caging space and optimize the number of vehicles needed.
- Set Cover Problem: Used to generate vehicles targets such that they cover the barrier walls found in the previous step.
- Charged Particles Problem: Used to generate the targets for the vehicles around the unit sphere.
- Linear Bottleneck Assignment Problem: Used to assign vehicles to their positions, both for prismatic and spherical cage types.
More details can be found in our paper [1].

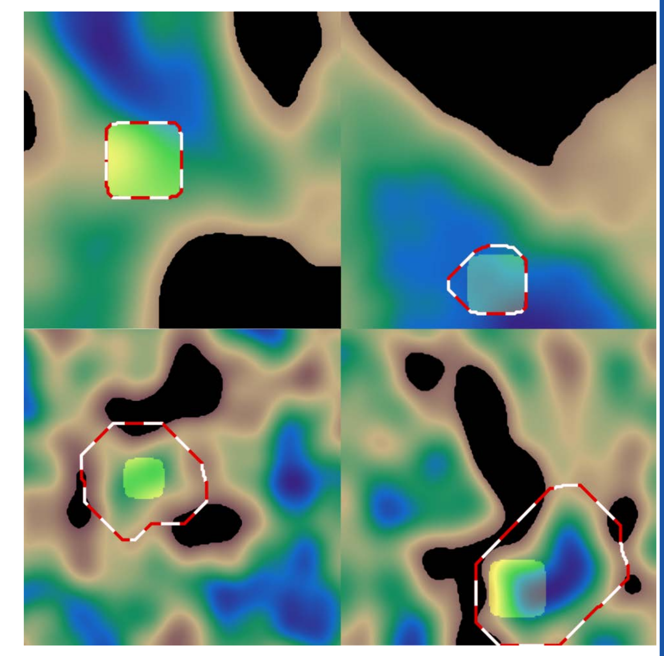
Results



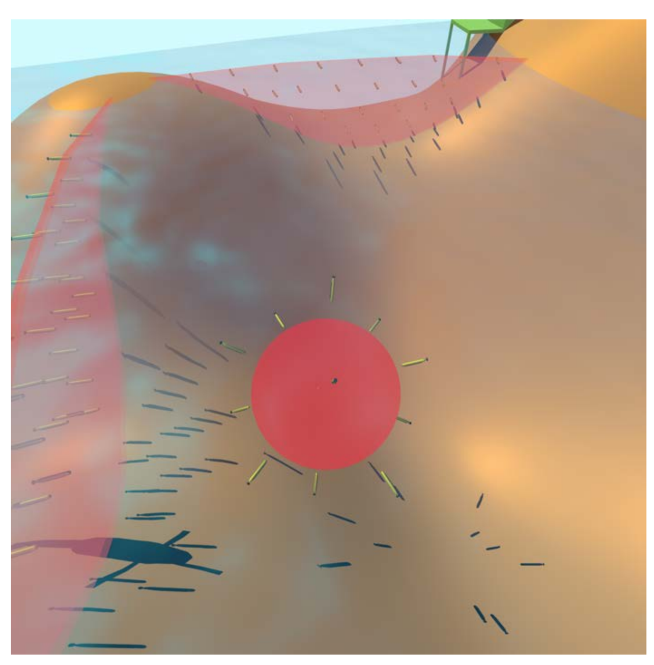
Initial input to the algorithm is a sighting of the evader. The source could be anything from a person to stationary sensors.



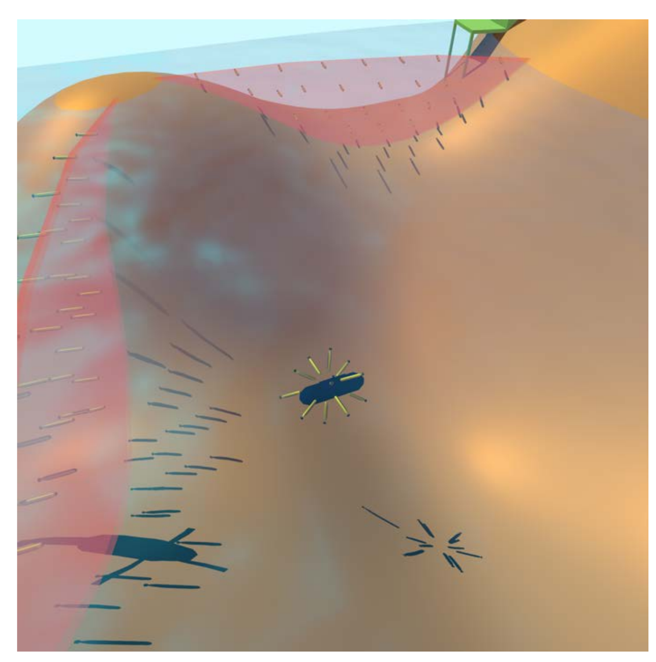
The vehicles are deployed to the computed cage walls. At this point the invader is contained to a known volume.



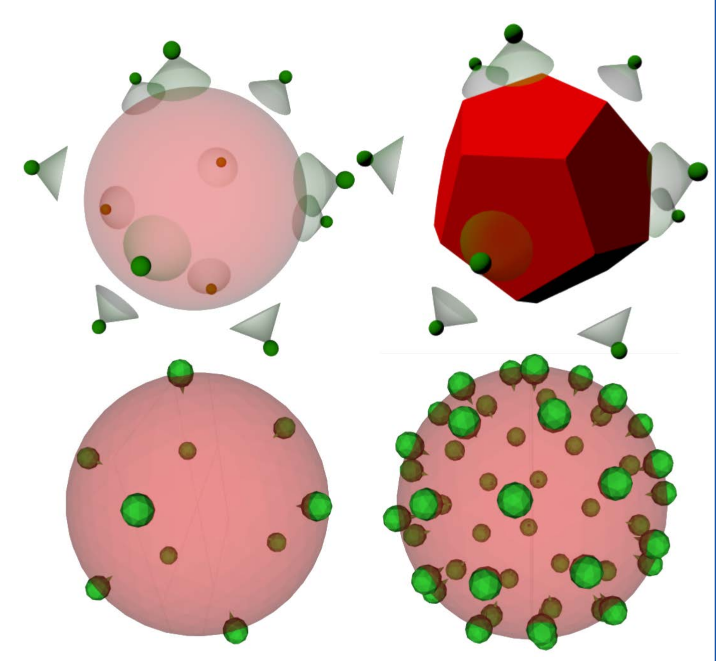
Diffent prismatic cages that maximize the utilization of the geography in order to minimize the number of vehicles



After a secondary sighting by the vehicles, a spherical cage is constructed using the now-nearby vehicles.



Now the spherical cage can be shrunk until the evader is captured.



Different spherical cages created with different number of vehicles and different sensor models

Outlook

Our current results show that utilizing multiple vehicles is beneficial.

We are currently working on utilizing Behaviour Trees for coordination and safety while executing such missions.

In addition, we are also working on formulating efficiency metrics for multi-vehicle coverage tasks in order to create an improved coverage technique that takes into account the intricacies of the underwater domain. Our preliminary work indicates that there is much to be gained in this area.

References

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FMV
Göteborgs Universitet
MMT
SAAB
Stockholms Universitet
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Contact Information :
- Web: https://www.smarc.se
- Email: ozero@kth.se

Robust Underwater Communication

Viktor Lidström[1] and Magnus L. Nordenvaad[2]
[1]KTH, Department of Engineering Mechanics
[2]FOI, Department of Underwater Research

Introduction

Communication under water is characterised by the absorption of most types of signals, e.g. optical and radio, at distances larger than 10-100 meters. For longer ranges, acoustic waves remain the only option, although they too are absorbed with increasing frequency; leaving only a useful frequency range of up to hundreds of kHz. The acoustic underwater channel is possibly the most challenging channel encountered: limited bandwidth, multitude of echoes from the surface, bottom or water layers, non-stationary conditions due to surface waves, and a dependence of most parameters on season, sea conditions, water salinity, temperature, depth, and sea bottom composition. This makes the channel unpredictable; models are generally insufficient for complete evaluation of communication methods, and rigorous testing in the field is generally required [1].

Aim

The aim of this PhD project is to evaluate and improve available robust methods, in order to establish the highest possible performing baseline for underwater modems. These have been explored historically, but recent advances in the communication field allow for significant improvements.

Objective

The objective is to design robust communication methods that are tailored to specific applications; being robust in the applied underwater environment, while maximising the information throughput, and minimising the energy consumption of modems.

Methodology

Two of the main channel difficulties are time- and frequency spreading; a signal becomes spread in time because of the arrival of multiple echoes, and spread in frequency because of echoes from surface waves having different Doppler shift. Robustness may be achieved by parallel transmission of sinusoids with different frequency, which are separated in frequency by guard bands, and transmitted signals are separated in time by time guards. Signals are commonly transmitted omnidirectionally, and another method of improving robustness is to use directional signalling; reducing echoes and improving the signal strength. Also, new high performing codes are of interest in this work, e.g. Polar Codes [2][3].

Results

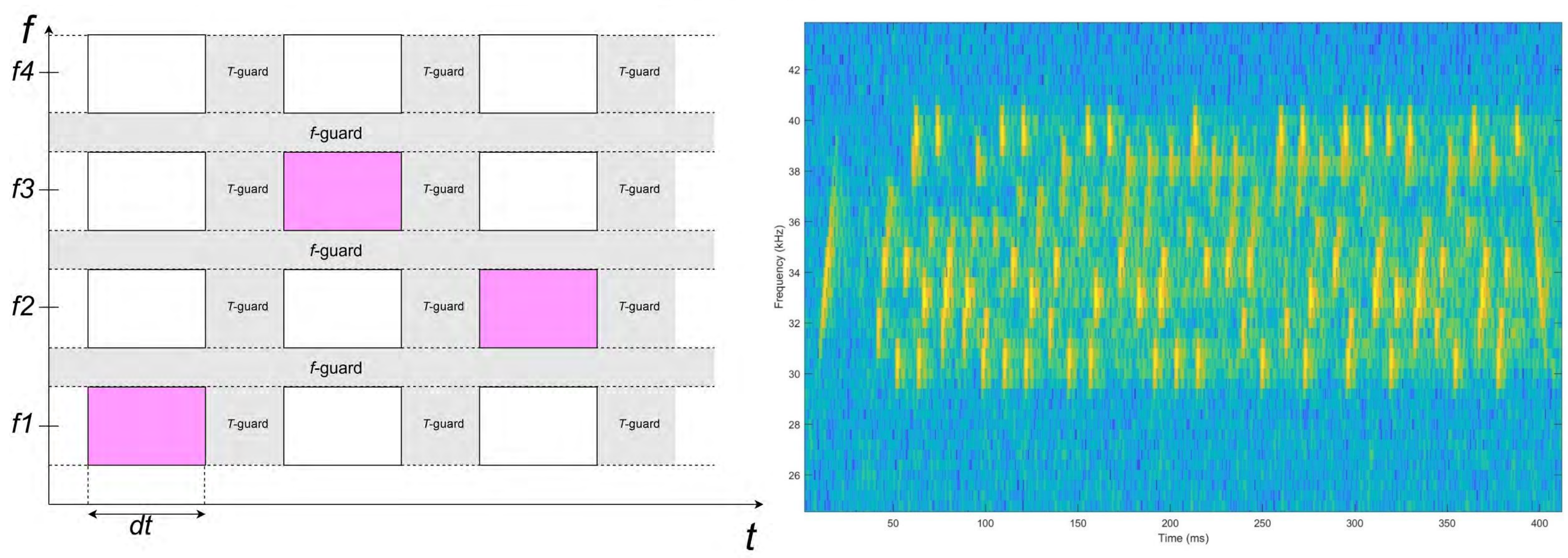

Figure 1: Depiction of signalling using sinusoids with different frequencies and time- and frequency guards (left), and the spectrogram of a received signal in a multi-echo environment from sea-tests in Ulvsundasjön in 2019 (right).

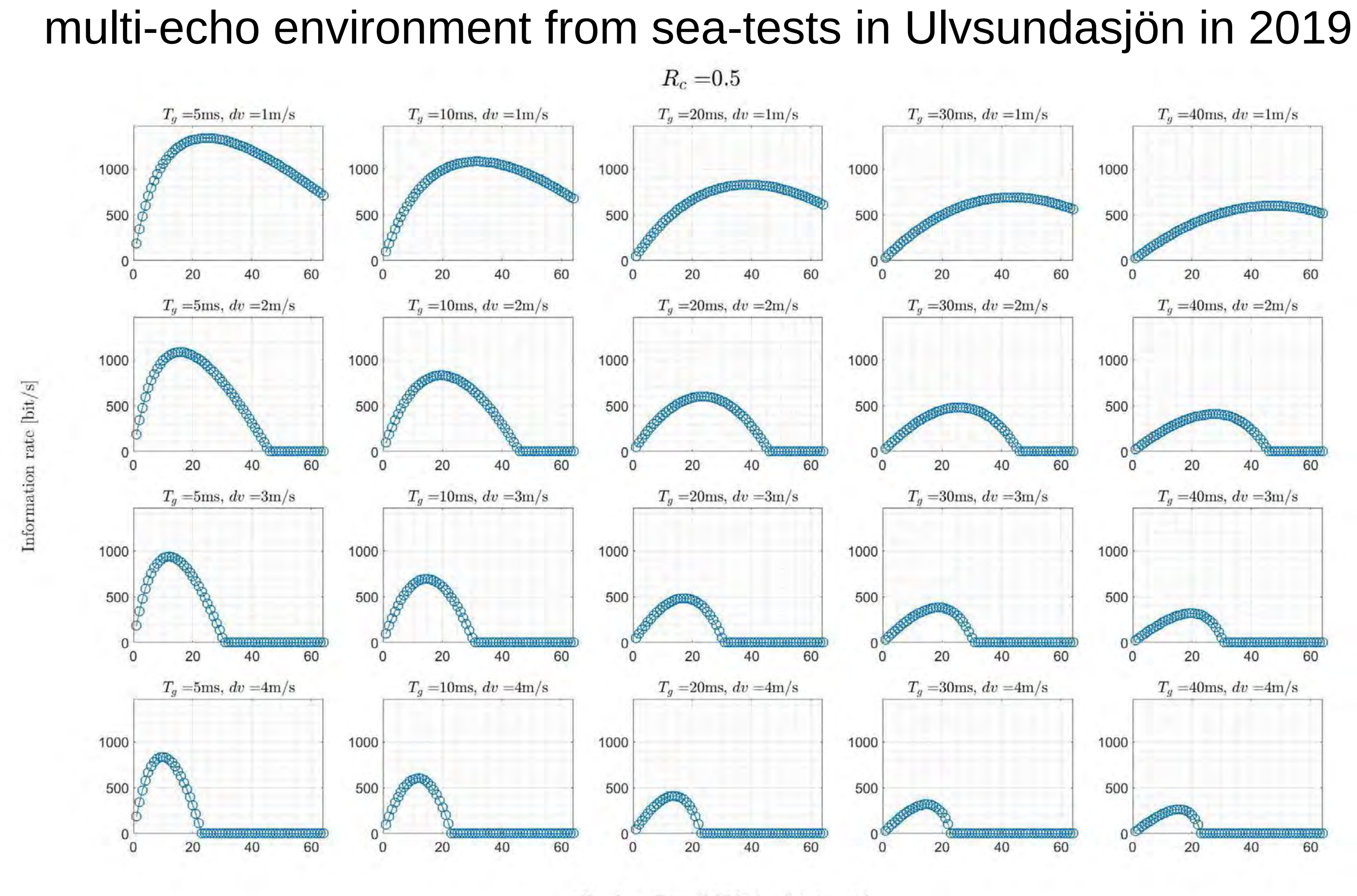

Figure 2: Possible information rates for a method using blocks parallel in frequency, in which one out of four information-bearing sinusoids are transmitted. Rates are plotted for different time guards (horz.), and frequency guards (vert.), which depend on the particular communication channel.

Outlook

Polar Codes have yet to receive extensive application in the underwater channel. Applying the robust methods described here in difficult environments with high time variability is also of interest, as this is where they might have the most to offer. Directional transmission and reception will possibly make the communication channel easier because of the reduced number of reflections, and improve the received signal power because of directivity. This also has applications for covert communication, low interference multi-agent networks, and navigational aid, as a network of directional modems could form a local coordinate system for an underwater vehicle.

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Contact Information :
- Web: https://www.smarc.se
- Email: viklid@kth.se

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