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VISION

Our vision is to leverage the competencies of the complete Norwegian maritime cluster and consolidate Norway as a leading global actor within autonomous ships.
OBJECTIVE

The Centre for Research-based Innovation within Autonomous Ships will develop and manage technologies, systems and operations for safe, sustainable, secure and cost-effective autonomous sea transport operations.

The focus areas include:

- Enabling technologies like situational awareness, artificial intelligence, autonomous control and digital infrastructure.
- New business models and operational concepts like the adaptation of remote operation centres (ROC) and the development of cost-efficient logistical concepts and port solutions.
- Methods and models for monitoring risk and the clarification of the legal aspects of liability when a captain is not on board.
Since the inception of SFI Autoship on December 1st 2020, great effort has been put into hiring excellent researchers, defining the scope of the use cases, and setting up and promoting the Centre's activities. The main strength of SFI AutoShip is the diversity of its consortium, which includes technology suppliers, end users, public authorities and research institutions. In this way, it is ensured that the Centre's researchers are tackling problems of direct relevance to the industry, with high potential for innovations that will contribute to establishing Norway as a leader within autonomous ship technology.

In 2022, the consortium was strengthened by the arrival of two new partners, Fugro and Reach Subsea, who are supporting Use Case 4 (offshore operations). The Centre's research capacity reached 14 PhD students and 3 Postdoctoral researchers, while 26 Master students graduated. A few highlights of our research activities include contributions to the 3-week trial of milliAmpere 2 (the world's first urban autonomous passenger ferry!) during September/October in Trondheim, two feasibility studies and numerous publications on the Centre's core research topics. In addition to producing and publishing their results, our researchers have had the opportunity to participate in regular colloquiums covering a wide range of topics, such as administrative information, innovation and technology readiness levels and partner presentations. These developments were presented to the consortium in detail during the SFI days, our main annual event that took place in October and involved strong contributions by our partners.

Visibility externally continues to be a priority for us. In 2022, the Centre was presented to Minister of Trade Jan Christian Vestre at a visit to Nyhavna arranged by the Ocean Autonomy Cluster. The milliAmpere 2 trial received great media attention, resulting in a large number of articles published both in Norway and internationally. Moreover, the Centre's structure and activities were presented to many events, including a workshop organized by the Norwegian Maritime Authority (NMA), as well as the SMASH! (Netherlands Forum Smart Shipping) delegation from the Netherlands.

SFI AutoShip is now entering its next phase, where tight collaboration between industry and researchers is the top priority. Research activities are on track on the various research topics, and we expect to see the early results emerging from a number of planned activities in the year to come. As results from the research becomes tangible, the focus will increase on opportunities for knowledge transfer and utilization of the research. In 2022 the innovation and commercialisation advisory committee has established a framework for knowledge transfer, ready to be applied in the years to come. I am proud and grateful for the combined effort from all partners during 2022, and look forward to see the consortium get closer to its full potential in 2023!

Anastasios Lekkas
Centre Director SFI AutoShip
2022 has been another exiting year for the SFI where most PhD and postdoc positions have been recruited, research activities have really come up to speed and we start to see tangible results in several areas. One of the major events was the trial period of the milliAmpere 2 in September 2022 which got a significant attention in the media and provided valuable input to further research in several work packages.

Going forward, the focus will now be on engaging industry partners and make specific links between researchers and industry experts to assure that the research activities are linked to industry needs and enable research driven innovations. This was a topic during the site visit by the Research Council to the SFI in June 2022. Specific actions have been initiated to assure this by setting up meetings with industry partners and the SFI to identify activities and links.

The first industry workshop was between Kongsberg Maritime and SFI AutoShip in October leading up to the SFI Days in Trondheim. Industry workshops are planned with all industry partners going forward. The SFI days was a success with very good attendance and interesting contributions from research partners and industry partners and a special focus on use cases.

The next phase of the SFI is also marked by a change in the governance and management of the SFI. A new administration was introduced in Q3/2022 and as Chairman of the board, I would like to express big tanks to the Centre director and Administrative coordinator who has done a fantastic job in the start-up of the centre during challenging times with the pandemic! Likewise, thanks to the new Center Director and Administrative coordinator that have initiated the next phase with a lot of positive energy and ideas, and I'm sure they will lead the SFI in the right direction! 2022 also marks the end of the period for me as a Chairman of the Board, and Hans Anton Tvetet from DNV has been announced as the new Chairman. It has been a honor to be leading the board during this phase and all the best wishes for my successor!
SFI Autoship Facts 2022

8 WORK PACKAGES

25 PARTNERS

PhD

PostDoc
Organisation

The Centre is hosted by the Department of Engineering Cybernetics (ITK) at the Faculty of Information Technology and Electrical Engineering (IE), NTNU. The Centre organisation includes the Centre Board, Centre Management, eight Work Packages (WPs), and two advisory committees.

In total, NTNU is involved with six Departments in three Faculties. IE Faculty: ITK, Department of Electronic Systems (IES), and Department of ICT and Natural Sciences (IIR). Faculty of Engineering (IV): Department of Marine Technology (IMT) and Department of Ocean Operations and Civil Engineering (IHB). Faculty of Architecture and Design (AD): Department of Design (ID).

The other research partners are SINTEF Ocean, SINTEF Digital, Institute for Energy Technology (IFE), and the University of Oslo (UiO).
## CENTRE MANAGEMENT

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<th>Name</th>
<th>Dept. of Engineering Cybernetics, NTNU</th>
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<tr>
<td>Anastasios Lekkas</td>
<td>Dept. of Engineering Cybernetics, NTNU</td>
<td>Centre Director</td>
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<tr>
<td>Ingrid Bouwer Utne</td>
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<td>Co-director</td>
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<tr>
<td>Trond Johnsen</td>
<td>SINTEF Ocean</td>
<td>Co-director</td>
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<tr>
<td>Kjell Olav Skjølsvik</td>
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<tr>
<td>Ingeborg Guldal</td>
<td>Dept. of Engineering Cybernetics, NTNU</td>
<td>Administrative Coordinator</td>
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## CENTRE BOARD

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<tr>
<td>Sverre Rye Torben</td>
<td>Kongsberg Maritime</td>
<td>Chairman of the Board</td>
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<tr>
<td>Kjell Røang</td>
<td>Forskningsrådet</td>
<td>Observer</td>
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<tr>
<td>Ingelin Steinsland/Ingrid Schjølberg</td>
<td>NTNU</td>
<td>Board member</td>
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<td>Trond Solvang</td>
<td>UiO</td>
<td>Board Member</td>
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<td>Sture Holmstrøm</td>
<td>SINTEF AS</td>
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<td>Arne Fredheim</td>
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<td>Bjørn Axel Gran</td>
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<td>Hans Anton Tvete</td>
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<td>Trygve Christian Moe</td>
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<td>Kjetil Skaugset</td>
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<td>Jan Cees Sabel</td>
<td>Fugro</td>
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<td>Jonathan Harcourt</td>
<td>G2 Ocean</td>
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<td>Ingvild Høgenes Nilsen</td>
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<tr>
<td>John Gabriel Østling</td>
<td>Grieg Star</td>
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<td>Andreas Simskar Wulvik/Torbjørn Pedersen</td>
<td>Idletechs</td>
<td>Board member</td>
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<td>Sverre Rye Torben</td>
<td>Kongsberg Maritime</td>
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<td>Hugo Rosano</td>
<td>MacGregor</td>
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<tr>
<td>Stephanie Kemna</td>
<td>Maritime Robotics</td>
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<td>Tom Eystø</td>
<td>Massterly</td>
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<td>Kenneth Johanson</td>
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<td>Bjørg Mathisen Døving</td>
<td>Reach Subsea</td>
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<td>Henning Huuse</td>
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<td>Stein Andre Herigstad-Olsen</td>
<td>Torghatten</td>
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<tr>
<td>Trond Langemyr</td>
<td>Kystverket</td>
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<td>Håvard Gåseidnes</td>
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<td>Terje Meisler</td>
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<td>Trondheim kommune</td>
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### INNOVATION AND COMMERCIALISATION ADVISORY COMMITTEE

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<tr>
<td>Kjetil Skaugset</td>
<td>Equinor</td>
<td>Leader (2021-2022)</td>
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<tr>
<td>Are Jørgensen</td>
<td>DNV</td>
<td>Permanent member</td>
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<tr>
<td>Oda Ellingsen</td>
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<td>Permanent member</td>
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<td>Vegard Evjen Hovstein</td>
<td>Maritime Robotics</td>
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<td>Trond Johnsen</td>
<td>SINTEF Ocean</td>
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<td>Kjell Olav Skjølsvik</td>
<td>NTNU</td>
<td>Permanent member</td>
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<tr>
<td>Bjørn Martin Worsøe</td>
<td>Telia</td>
<td>Member (2021-2022)</td>
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<tr>
<td>Joachim Ofstad Næss</td>
<td>Torghatten</td>
<td>Member (2021-2022)</td>
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### SCIENTIFIC ADVISORY COMMITTEE

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<tr>
<td>Thor I. Fossen</td>
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<tr>
<td>Paolo Braca</td>
<td>Centre for Maritime Research and Experimentation (CMRE), NATO Science and Technology Organization</td>
<td>Member (2022-2025)</td>
</tr>
<tr>
<td>Nikolaos P. Ventikos</td>
<td>School of Naval Architecture and Marine Engineering, National Technical University of Athens (NTUA)</td>
<td>Member (2022-2025)</td>
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Research and Work Packages

Based on the Centre's objectives two overarching research questions have been identified:

- How can society benefit from autonomous shipping, in terms of reduced environmental footprint, economy, safety and sustainability?
- How can new standards, methods, regulations, digital twins and digital infrastructure be used to assure the required safety and security for autonomous shipping?

Answering these questions relies on a multi-disciplinary effort, multiple perspectives from different autonomy concepts, industrial and commercial applications, and the Centre stakeholders' interests, theory development, and experimental testing. This is best approached by framing and aligning Centre research according to use cases, where each use case represents a relevant context for autonomous ships.

We have 8 Work Packages in SFI AutoShip, 7 of which are devoted to research, use cases, innovation and commercialization, and 1 to management, communication, and dissemination. Work Packages 1-7 are presented on the following pages, which shows the ongoing research activities in the Centre. Some highlights from the final Work Package can be found in the subchapter on News and Events.
AutoRemote

WP Leader: Associate Professor Edmund Førland Brekke
NTNU, Department of Engineering Cybernetics

Our objective is to develop perception and decision-making systems that will enable maritime autonomous surface ships (MASS) to accomplish their mission, including fallbacks for extraordinary events.

The work in WP1 has focused on the fundamental capabilities that are required to improve the safety and efficiency of the state of the art in maritime surface autonomy. This includes the design of algorithms suitable for localization, docking and collision avoidance in coastal waters. Furthermore, to support such advances, the work includes tools for data gathering, sensor calibration, and algorithms for improved situational awareness.

Photo: Sander Furre
Emil Martens
Multi sensor detection for autonomous surface vehicles

Background and motivation for the research
To operate autonomously, a surface vehicle requires good situational awareness. This includes knowing where it is safe to navigate, how other agents move and what objects are in the area of operation. This information must be detected, which is what the work of this PhD will focus on. How can we use a combination of multiple sensors to improve the detection capabilities of autonomous surface vehicles?

Objective and main tasks
As new combinations of sensors will be used in the researched, the availability of relevant public data sets is limited. Therefore, the first step in the research will be to develop a novel sensor platform that can be used to effectively gather training data for later use. The acquired multi sensor data will be used in the development of novel methods that hopefully will give improved detection capabilities to autonomous surface vehicles.

Henrik Dobbe Flemmen
Simultaneous localization and mapping (SLAM) for autonomous ships

Background and motivation for the research
Both autonomous ships and traditional ships rely on GNSS (Global Navigation Satellite System) for navigation. GNSS is an excellent system for localizing the ship with high accuracy and integrity, but autonomous ships need a redundant localization system to use when GNSS is not available. One potential technology to gain this redundancy is SLAM. SLAM is the problem of creating a (not necessarily human readable) map of the environment around the ship and repeatedly finding its position in the map.

Objective and main tasks
The objective is to develop algorithms to solve SLAM for autonomous ships. This will be a combination of adapting existing SLAM algorithms made for other platforms to ships and creating new solutions, and implementing the different algorithms and test them on recorded data.

Expected results and innovations, and industry collaboration
The project expects to provide an algorithm which solves SLAM for ships to a sufficient degree. This could then be implemented into existing products or be used in new products by the industry partners. Kongsberg Maritime has provided relevant data recordings.

An illustrative image of the type of output the research aims to deliver. If the goals are met, the detection should also work in challenging conditions like during heavy rain, fog or snow.

Radar is a highly relevant sensor for maritime SLAM. This example image shows the ship in the center and land as yellow dots. The task is then to create a map of the surrounding islands and use that map to locate the ship. Image is provided by Kongsberg Maritime.
Daniel Menges

Situational Awareness of Autonomous Ships using Digital Twins

**Background including motivation for the research**

I hold a master’s degree in mechanical engineering specializing in robotics and autonomous systems. During my studies, I mainly focused on control theory and machine learning.

This PhD project aims to improve the situational awareness of autonomous vessels. Autonomous sea operations depend on a reliable perception of the environment and a sophisticated situational awareness of the ship’s conditions. The enhanced perception can supply controllers with extended information to improve the overall decision-making process. Key enablers for testing such modern algorithms in a safe environment are digital twins. Digital twins allow the simulation of several events, including critical collision avoidance scenarios. For this purpose, a well-developed digital twin has to map reality with precise models and real-time data streams.

**Objective, main tasks and approach**

The research will develop algorithms for improving the situational awareness of autonomous ships, and a digital twin of an autonomous ship and its environment.

Problems concerning the ship’s situational awareness are tackled using control theory and machine learning. A digital twin environment for safe simulations will be implemented with the Unity game engine.

**Expected results and innovations**

Expected results are novel approaches and algorithms for improving:

- External situational awareness, including accurate estimation of the forces impacted by wind, waves, and sea currents, and estimation of the position and motion of other vessels, and
- Internal situational awareness, with condition monitoring of the ship's components (e.g. engines via thermal cameras).

The project will also develop an extendable digital twin framework for autonomous ships and their natural environment.

**Use-case involvement and industry collaboration**

We strive to develop a digital twin environment where algorithms concerning multiple use cases can be simulated and tested. We collaborate with Idletechs AS. They provided data from thermal camera images of a ship’s engine. This allows us to investigate the internal conditions of a ship.

**Activities and results in 2022**

During 2022 work has focused on a disturbance observer framework that can reconstruct the forces on a vessel impacted by wind, waves, and sea currents, and condition monitoring and forecasting of a ship's engine using a thermal camera.
Simon J.N. Lexau  
Docking For Autonomous Ships

Background including motivation for the research
Unmanned Surface Vessels (USVs) have the potential to revolutionize the shipping industry by reducing the cost and risk associated with human error, and improving the overall efficiency of the industry. My research focuses on developing a system for autonomous ships to dock at ports in a safe and efficient manner, taking into account the challenges of nonconvex harbor geometries, static and dynamic obstacles, and real-time computational demands.

Objective, main tasks and approach
The objective of my research is to develop a system for autonomous ships to safely and efficiently dock at ports, utilizing advanced technologies, in collaboration with industry partners, to test and validate the system in real-world scenarios.

To achieve this, my research includes a thorough literature study and a map-based simulator to test docking algorithms in any Norwegian harbor, and the milliAmpere ferry will be used as a testbed. Some of the technologies that will be pursued are geometrical algorithms for high-level decision-making, model predictive control for trajectory planning, reinforcement learning, and other low-level controllers for trajectory tracking and obstacle avoidance.

Expected results and innovations
The ultimate goal of my research is to develop a system that can safely and efficiently dock autonomous ships at ports, taking into account the unique challenges of harbor geometries, static and dynamic obstacles, and real-time computational demands. This will significantly reduce the cost and risk associated with human error, and improve the overall efficiency of the shipping industry. Additionally, the system will be able to adapt to changing conditions and unexpected situations, making it more resilient and reliable.

Use-case involvement and industry collaboration
My research is in collaboration with Kongsberg Maritime and Equinor, and will be simulated on large container vessels, which experience significant wind disturbance at low speeds. The results of my research can be applied to a wide range of use cases, including cargo ships, passenger ships, and leisure vessels.

The figure illustrates the use of the map-based simulator, SimCharts, to display the results of a model predictive control-based docking algorithm. The simulated environment includes other vessels, which are generated from AIS data collected in Trondheim harbor at the time of capture.
Trym Tengesdal, postdoc
Machine learning for adapting COLREGS compliant collision avoidance algorithms for autonomous ships

Background including motivation for the research
The image below shows a situation in inland-waters with the own-ship (OS) in blue, where the OS should adhere to the traffic rules, avoid ship collision and avoid grounding. This is a challenging problem, as the geography and nearby vessel configuration varies over time. The problem here is thus how to adjust the collision avoidance planning algorithm behavior based on historical data from such situations. This will aid in making the algorithms deployable in a diverse set of conditions.

Objective, main tasks and approach
The main objective of the research is to apply machine learning and data-driven methods in order to adapt and automatically adjust the behavior of automatic collision avoidance planning algorithms.

A first step in achieving this will be to develop a simulation and evaluation framework for testing and validating such algorithms, which will aid in achieving the main objective.

The work in the postdoc will be performed through software programming, mainly in Python. Simulations will mostly be considered.

Expected results and innovations
Expected results from the research are a simulation and evaluation framework which can be used to validate new/existing COLAV algorithms, as well as methods for automatically adjusting new/existing COLAV algorithms based on simulated/real data (from e.g. Automatic Identification System transponders).

A situation in inland-waters with the own-ship (OS) in blue, where the OS should adhere to the traffic rules, avoid ship collision and avoid grounding.
Digital Infrastructure

**WP Leader: Professor Pierluigi Salvo Rossi, NTNU, Department of Electronic Systems**

*Our objective is to develop reliable and secure data transfer among the ship, the RCC and other marine traffic, allocated according to operational needs.*

The digital infrastructure behind autonomous maritime systems is an IoT system, where nodes are sensors on ships or on-land centres, each with different partial view, different equipment, asymmetric links, and operating in non-stationary local and global conditions.

Understanding and comparing effective ways to collect and combine the information and provide a coherent scenario is challenging.

In 2022, the framework of collaborative collision avoidance of autonomous ships has been explored and existing gaps identified. The work has covered the hybrid case in which both autonomous and conventional ships interact. Additionally, the integration of information provided by multiple radars has been considered to deal with challenging tasks such as detection and tracking of small targets in large surveillance areas.

*Photo: Sander Furre*
Melih Akdağ
Collaborative Collision Avoidance for Autonomous Ships

Background and motivation for the research
As the maritime industry continues to evolve, the coexistence of autonomous and conventional ships is becoming increasingly important. The collaboration between autonomous and conventional ships, as well as with shore control centers and Vessel Traffic Services (VTS), is crucial for ensuring the safe and efficient operation of maritime traffic in the future. This collaboration is made possible through the concept of information and route exchange via AIS and VDES, which allows for data communication and coordination between all parties involved. By leveraging advanced technologies such as artificial intelligence, the maritime industry can continue to improve safety, efficiency, and sustainability.

During 2022 we conducted a literature review to gain an understanding of the previous works related to collaborative collision avoidance of autonomous ships and to identify any gaps in the field. Based on our findings, we proposed a high-level framework to guide our work on developing an algorithm for collaborative collision avoidance between multiple autonomous and conventional ships. We then worked on developing a reactive collision avoidance algorithm which utilizes the information exchange between vessels and considers both static and dynamic obstacles and the COLREG rules. The results are presented at the 14th IFAC CAMS 22 conference.

Building on this, we are working on developing a mid-level planner that would collaborate with other ships in advance and calculate collision-free route plans to be exchanged between ships to convey intentions.

Objective, main tasks and approach
The objective of this study is to design a collaborative collision avoidance algorithm that enables the autonomous ship to communicate with other ships and shore facilities for creation of collision-free and efficient trajectory plans.

To obtain our main goal, the research methodology for 2023 is divided into objectives as follows:
- Developing a hierarchical algorithm consisting of mid-level and reactive path planners and utilizes information exchange between ships.
- Evaluating the performance of the algorithm with computer simulations of predefined scenarios covering grounding hazards, cooperative and non-cooperative vessels, and the COLREG rules.
- Validating the performance of the developed algorithm with multiple autonomous and human-operated ships at sea trials.

Expected results and innovations
The project expects to enhance navigational safety and operational efficiency by enabling collaboration between autonomous and human-operated ships.

Use-case involvement and industry collaboration
The algorithms are developed considering container ships navigating in fjords, ports, and hinterland. We are in collaboration with the partners of the Use Case 2 Short Sea Container Shipping.

Trajectory plan calculated by the hierarchical collaborative collision avoidance algorithm.

Using ship-to-ship route exchange concept with AIS and ECDIS integration. Image from Sjöfartsverket.
Lukas Herrmann
Ship-Shore Radar Network

Background including motivation for the research
The concept of autonomously operating ships implies situational awareness, intelligent collision avoidance techniques, and guidance and control of unmanned vessels. Therefore, information about the vessels positions and their surrounding environment must be well known. This information can be obtained by surveillance radars, as radar technology provides long range capability, velocity information, and it is robust against e.g., changing light conditions, rain, and fog. Distributing target tracks will thus contribute to the situational awareness of the observed area.

Objective, main tasks and approach
The PhD project focuses on establishing a network of maritime radars to be utilized for both monitoring and guiding autonomous vessel. Specifically, developing methods for reliable target detections, even for small vessels in a large surveillance area, and sensor fusion to provide high quality target tracks. The whole development process will be based on real world data obtained from observations of the Trondheim fjord.

One of the key methods is to implement various concepts and evaluate them on real life data sets to combine, transfer, and improve existing algorithms as well as develop new ones. The data sets will be provided by the radar system to be established as part of the project.

Expected results and innovations
The expected outcomes are improved detection and tracking algorithms applied to real world maritime scenarios towards a level contributing to autonomous shipping applications, ideally with implementations on real life platforms.

An illustration of the planned surveillance radar network covering parts of the Trondheim fjord.
Our objective is to develop safe and efficient human-machine interfaces and interaction for remote operation centres (ROCs).

Maritime Autonomous Surface Ships (MASS) will for the foreseeable future be dependent on a land-based remote operation centre (ROC). The role of the ROC will be to monitor the status of the ship, and to intervene if the automation fails. The location, removed from the context of the vessel, will be a great challenge in order to give adequate situation awareness to the ROC operators. The interaction between MASS-ROC and conventional ships will depend heavily on sensor and AIS information, as well as cooperation with the vessel traffic service (VTS).

MASS will also need to communicate their state and intention to passengers and remaining crew onboard, as well as other ships in the vicinity.

In 2022 Work Package 3 has onboarded a new Post Doc who is working on remote crane operations and graduated 4 master students related to the SFI. 14 papers have been published and 58 popular science dissemination activities has been carried out. In addition, the Work Package leader started the project “Man in future maritime operations” (MIDAS, NFR Kapasitetsløft), which will be a dissemination platform for SFI AutoShip. Further, WP3 have been central in the trial of milliAmpere2, and have now collected much data for future publications. All these activities have contributed to reaching the Centre’s objectives in 2022.
Andreas Nygard Madsen

AI decision transparency in autonomous shipping

Background including motivation for the research
I have a background as a mariner within offshore operations and passenger ferries. My main motivation for a PhD study is my aspiration to discover and learn new things, as well as to be able to see things from a different perspective. The opportunity to further develop skills to solve complex problems motivates and gives me energy.

Objective and main tasks
The goal of this PhD is to develop strategies for AI decision transparency in autonomous shipping. The main research question for the PhD is:

How can a decision support system for a remote operator of a marine surface ship be part of a resilient integrated system to ensure and maintain a reliable situational awareness?

RQ1: How can decision transparency in an AI system be defined and what is the state-of-the-art research within the concept traffic alert and collision avoidance systems with respect to decision transparency?
RQ2: What is required to enhance decision transparency in an AI system with respect to autonomous shipping?
RQ3: What strategies can be used to enhance and maintain the situational awareness of a remote operator?

Research approach/ methodology
For RQ 1 a state-of-the-art literature review will be carried out to facilitate the process of finding suitable measures to ensure safe operations of marine surface ship in the context of decision transparency for a remote operator. This work is in progress and expected to be completed by summer 2023.
For RQ 2 stochastic models (e.g. cluster analysis) and XAI will be used to model when an autonomous system should be in autonomous mode, and when to raise a red flag to alert an remote operator. The focus will be on which attributes should be monitored and which metrics should be used as a basis for the machine learning algorithms. This work has been completed.
For RQ3 distributed situational awareness (DSA) theory will be utilized in exploring the possibilities of enhancing the collaboration between an AI system and the crew/remote operator. This work is in progress and expected to be completed by autumn 2023.

Expected results and innovations
The goal of this PhD is defined as “Developing strategies for AI decision transparency in autonomous shipping” to benefit the stakeholders in the SFI Autoship. The cluster analysis sets out to define a set of situations that programmers and designers may apply in the development of AI-systems and support systems. With the decision transparency strategies proposed in this PhD project, one can assume that it will contribute to the development of decision support systems, ultimately leading to improved efficiency and safety.

Use-case involvement and industry collaboration
Kongsberg Maritime in Ålesund has contributed with testing of decision support (ANS) in simulator.

Figure 1: Illustrating a point of no return (X) where vessel A must make a decision to uphold her CPA/TCPA limits and an extended timeframe for AI decision (ETAD). The decision to apply ETAD must be based on either a statistical significance, or a human decision.

Figure 2: Design sketch for visualization of ETAD, illustrating that an adjustment of course or speed needs to be larger, the longer one awaits a maneuver.
Felix-Marcel Petermann

Interaction Design for Autonomous Ships

Background including motivation for the research
My background includes a bachelor’s degree in Applied Life Sciences and computer science courses, as well as a Master’s degree in Human Computer Interaction and Social Media from Umeå University. Before starting my PhD, I worked as a User Experience and Interaction Designer at an industrial design studio where I contributed to projects in various fields, including transportation, construction and medical.

Objective and main tasks
As a doctoral candidate in Interaction Design for Autonomous Ships, my passion lies in developing interfaces and physical products that prioritize the user experience. My research centers on creating a satisfactory and efficient environment for operators, passengers, and other stakeholders in the environment of autonomous ship, e.g., remote-control centers. By utilizing user-centered design methods, my goal is to bring increased situational awareness to the “black box” of remote operating centers, and to enhance navigational safety through the incorporation of spatialized sound and an LED setup. I am dedicated to pushing the boundaries of design in the exciting field of autonomous ship technology.

Research approach/ methodology
My research approach encompasses a blend of methodologies, like quantitative and qualitative research methods with a strong emphasis on ethnographic studies in the current maritime industry to identify persistent issues on current ship bridges and areas that should be improved in new concepts for reduced crew and fully autonomous solutions. The ultimate goal is to create new concepts in the form of tangible and digital prototypes, evaluate them with the intended user group, and provide recommendations for designing a new collaborative working environment for humans and AI.

Expected results and innovations
As part of my research, I have been involved in the EU-funded Lashfire project, where a digital fire central for RoRo and RoPax ships was developed. This provides a solid foundation for remote hazard control. Additionally, during the public trial of milliAmpere 2 in the autumn of 2022, extensive observations and studies were conducted, including a study on the information needs of passengers on autonomous passenger ferries. The findings were published in a paper entitled “Interaction between humans and autonomous systems: Human facing explanatory interface for an urban autonomous passenger ferry”. Further results are expected from this trial. My work also includes the development of new concepts and prototypes, such as the LED solution and sound spatialization, which have the potential to lead to new products and design suggestions for Remote Operating Centers. Continuous dissemination of the work on different events like visits of ministers and interested parties is done.
Luka Grgicevic
Decision Support Systems for Autonomous Vessels

**Background including motivation for the research**
My background is in the field of control engineering and master's degree title, obtained at the University of Split in Croatia, was automatic ship positioning where I modelled and analyzed different control techniques for weather optimal positioning. One of the research challenges that overlaps with SFI AutoShip, will be to explore possible implementations of artificial intelligence in navigation. During these doctoral cross-disciplinary studies I hope to catch up with the latest achievements that combine computer and cognitive sciences.

**Objective, main tasks and approach**
I will be developing applications and algorithms for distributed systems that search for an optimal path for a vessel to follow. Those solutions might then serve an advisory role in the existing integrated navigation system and be a core part of a new ship bridge design, more suitable for Maritime Autonomous Surface Ships with higher autonomy levels.

Most of the research will be validated in a simulated environments via intelligent agents. If the results are proven impeccable, they will be tested on urban or car ferries in collaboration with Use Case 3 partners.

**Expected results and innovations and industry collaboration**
Decision support systems on conventional vessels will play a huge role in a gradual shift towards greater autonomy levels that will span over few decades from now. Results will certainly try to take into consideration that crew should understand and rely on meaningful advice received from the developed programs.

Collaboration with the industry partners affiliated with Use Case 3 are in the early stage.

Taufik Akbar Sitompul, postdoc

Human-machine interface for remote crane operation

Background including motivation for the research

Crane operators are traditionally controlled by operators who are present on-site. Although this operational mode is still common, there is an increasing demand towards remote operation, so that operators would not be exposed to accidents that may occur in their workplace. Despite its apparent benefits, remote operation presents a major challenge that does not exist in on-site operation, i.e., the amount of information that operators could receive remotely is far more limited than what they could receive by being on-site. This challenge makes remote crane operation more difficult than on-site crane operation.

Objective and main tasks

As the instrument used for information exchange between operators and their remote cranes, human-machine interface (HMI) plays an important role in facilitating safe remote crane operation. There is a need to design HMI that would help operators observe the work environment remotely, make correct decisions, and provide necessary inputs without causing excessive cognitive workload.

Research approach/methodology

To design HMI that could fulfill the need mentioned earlier, this project employs the following activities:

1. Conducting field studies and interviews with crane operators to understand current practices and challenges in both on-site crane operation and remote crane operation.

2. Designing user interface layouts and components that could help operators maintain awareness of the remote work environment and operating their cranes safely.

3. Evaluating various user interface layouts and elements by involving crane operators to determine which settings that would provide optimum results for remote crane operation.

Expected results and innovations

From the scientific perspective, this project would generate knowledge on:

1. How the shift from on-site crane operation to remote crane operation affects crane operators’ performance and experience.

2. How different user interface layouts and components will affect crane operators’ performance and experience.

From the innovation perspective, this project will generate a set of user interface layouts and components that crane manufacturers and third-party suppliers could adopt when developing their own HMIs.

Use-case involvement and industry collaboration

This research is involved in Use Case 2: Short-sea container shipping. In 2022, Taufik has conducted a field study at one of geared vessels, i.e., ships that have their own cranes on board, operated by NCL.

The comparison between on-site crane operation (left image) and remote crane operation (right image).
Eirik Fagerhaug

Explainable AI for Autonomous Ships

Background including motivation for the research
I have a Bachelor’s and Master’s degree in computer science related subjects and have worked as a software developer for a few years. It is my passion for the field that has led me to pursue a PhD in the SFI to enhance my own knowledge and to advance the field.

Objective and main tasks
My goal as a researcher is to make it easier for people who work at remote control centers to understand how artificial intelligence (AI) makes decisions when it’s in charge of running autonomous ships. To achieve this, I plan to use interactive visualizations that are based on geographic information systems (GIS). These visualizations will be designed to help people see and understand the thought process of the AI in a clear and intuitive way.

Research approach/ methodology
I am creating a virtual representation of the environment surrounding ships using aerial photography, LIDAR data, mapping software, a 3D engine and deep learning algorithms. These tools bring the virtual model to life in a realistic and interactive manner, providing a detailed and accurate representation of the ship’s environment.

Expected results and innovations
The project aims to establish a foundation for future software development at remote control centers, leading to the creation of more advanced tools for remote operators. By investing time and resources into this foundation, I hope to shape the future of remote operations and improve the technology used in these centers.

Use-case involvement and industry collaboration
I am involved in use case 2 for short-sea container shipping. Most of my current collaborations is with Kongsberg Maritime with the use of their ship simulators. I hope to be able to use my software together with their simulators to be able to test my results on real navigators.
Our objective is to research and develop novel methods, models and tools for risk management and safe design and operations of autonomous ships.

This work package focuses on risk reduction, mitigation strategies, and safe solutions for the design and operation of autonomous ships. This achievement relies on the ability to identify the new risks and incorporate necessary (technical, software, security, human and organisational) measures into the systems, the operation, and the associated infrastructure. In 2022 we consolidated the work of the PhDs and Post Doc and conducted a webinar on Software Risk of Autonomous Ships hosted by NTNU.
Susanna Dybwad Kristensen
Online risk modelling of autonomous ships

Background including motivation for the research
Autonomous ships are under development, however, risks must be assessed and controlled before these can be put into conventional operation. During operation, autonomous ships will be exposed to factors, such as degrading technical equipment and changing environmental factors. This may affect the risks and needs to be considered in the decision-making. This introduces the need for online risk modeling. Online risk models utilize different sources of data to estimate the risks related to autonomous ship operations, in order support decision-making for safer and more efficient operations.

Objective and main tasks
The objective of the PhD work is to research and develop online risk models for autonomous ships. The first main tasks will be to identify hazards related to autonomous ship operations, both with respect to safety and security. The second task is to investigate how the risk models may provide input for the autonomous ship control system, including how risk is measured and evaluated. A third task is to test the risk models and assess the effect on operational decision-making.

Research approach/ methodology
Both qualitative and quantitative methods will be used in the research. For hazard-identification, system-theoretic process analysis has been applied to autonomous ship operations. To incorporate the aspect of security, the use of system-theoretic process analysis for security has been investigated. For risk modeling, the use of Bayesian networks has been investigated.

Expected results and innovations
The expected result from the research are new online risk models for autonomous ships. This will build on the identification of safety- and security-related hazards for autonomous systems and operations, and investigation of the use of different risk modelling approaches. Further results include investigation of risk related to design and operation of systems relevant for use case 4 in the SFI.

Activities and results in 2022
In 2022, relevant activities have included participation in the 16th Probabilistic Safety Assessment and Management (PSAM) conference, and participation in field trials with USV Grethe in Trondheimsfjorden.
Raffael Wallner

Safety Demonstration of Autonomously Controlled Ships using Digital Twin

Background including motivation for the research
Safe operation is a crucial requirement for autonomously controlled ships. However, assuring safety under all conditions and circumstances is not a straightforward task due to the complexity of such systems. Furthermore, the self-learning and evolving characteristics of autonomous systems require safety evaluations throughout the whole life cycle.

An approach to test and verify safety in any state are safety demonstrations for potentially hazardous situations in simulations using a digital twin. Digital twins have been used in different domains for several years but approaches to represent autonomous systems with digital twins started only recently. Particularly for the application of safety demonstrations of autonomous ships, requirements of the digital twin need to be further elaborated.

Objective and main tasks
The objective of this PhD is to develop a methodology to verify safety of autonomous ships using digital twins in simulated safety demonstrations. The figure depicts a simplified verification process using simulated safety demonstration and lists necessary task for its realization.

Research approach/ methodology
- Research to collect requirements for digital twins and simulations in safety demonstrations
- Definition of structures and workflows
- Analysis to identify scenarios
- Implementation of safety demonstrations
- Test and verification of implementation

Expected results and innovations
It is expected to achieve innovative approaches towards the test and verification of autonomous systems in simulations applicable to design, production and operational phases.

Use-case involvement and industry collaboration
The scenarios for the research project focus on use case 4 related setups. Cooperation with industry partners within use case 4 and work package 4 is done by supervision, providing knowledge, data, facilities and collaboration.

Activities and results in 2022
- Published conference paper about approaches of using digital twins in safety verification
- Presented the paper at ESREL22 in Dublin
- Site visit and collaboration with IFE
- Use case meeting at Equinor
- Research in and preliminary work for upcoming publications on scenario identification and simulation workflow
- Course work
Spencer A. Dugan
Reliable design and operation of propulsion systems for autonomous ships

Background including motivation for the research
Two dominant trends in the maritime industry are the electrification of propulsion systems and the reduction of manning in the mission towards autonomous ships. Electric propulsion systems may suffer from complex failure modes and require complicated maintenance. Furthermore, critical failures at sea create unsafe conditions that may lead to loss of life and damage to the ship and/or environment.

Currently, the ship’s crew performs regular maintenance and facilitates onboard repairs. But an absence or reduction of crew in addition to the challenges of electrification pose reliability concerns for the safe operation of autonomous ships. The work explores how the reliability of autonomous ships can be improved through design or operational procedures.

Objective and main tasks
The objective is to develop knowledge and methods for reliability assessments for propulsion systems of autonomous ships. The three main tasks are outlined below:

• Improve understanding of the frequency, duration, consequences, and risk influencing factors of machinery failures for existing ships by analyzing incident databases
• Identify and analyze design solutions for machinery systems onboard autonomous ships
• Investigate operational requirements for power management and maintenance procedures considering crew reduction

Research approach/methodology
The research methodology begins with an analysis of incident databases containing observations and reports of vessel losses of command. System-based and risk-based ship design methods are candidates to quickly assess many potential design configurations. Lastly, reliability assessments of ship propulsion systems are mostly quantitative and utilize equipment failure data in their predictions. Investigating operational procedures will be done using a combination of qualitative and quantitative methods. STPA is noted for its applicability for assessing risk for complex systems.

Expected results and innovations
The work is expected to contribute to an improved understanding of the causes and consequences of vessel blackouts. The research will demonstrate the feasibility and limitations of different propulsion systems and topologies for autonomous ships.

Use-case involvement and industry collaboration
Use Case 3: Passenger Ferries

There is ongoing collaboration with Kystverket to analyze a database of observed vessel losses of command.
Ayoub Tailoussane

The application of the COLREGs to autonomous vessels, and the challenge of translating legal concepts into machine comprehensible data for the development of COLREGs-compliant autonomous vessels

Background including motivation for the research
After obtaining a Bachelor’s in Private Law and a Master’s Degree in Business Law, I worked as a Legal Counsel with the law firm CMS Francis Lefebvre Morocco for over two years.

I went on afterwards to complete an LL.M. in Admiralty & Maritime Law at Tulane University in New Orleans, Louisiana, USA.

I am currently pursuing a PhD at the Scandinavian Institute of Maritime Law at the University of Oslo with a focus on studying the Convention on the International Regulations for Preventing Collisions at Sea, 1972 (COLREGS) and the extent to which it can accommodate and apply to autonomous vessels.

The project aims to offer crucial insight to developers of autonomous collision avoidance systems on how the COLREGS are interpreted and construed from a legal point of view, and especially by the courts of Law of select jurisdictions. The development of autonomous vessels presents us with the unique opportunity of exploring topics which delve deeper into the relationship between Law and technology and how each may affect the understanding and development of the other.

Objective and main tasks
The main objective is to determine if the COLREGS are capable of being applied to autonomous vessels, and if so, to what degree. The COLREGS are a collection of legal norms, and as such they might not offer the level of precision and clarity that is often required or desired by programmers, engineers and other technical experts. Defining and understanding legal concepts is therefore a challenge, especially when a significant part of the rules cannot accommodate a precise quantification.

Through a legal analysis of the COLREGS which focuses on their interpretation and application by courts, the research seeks to identify where, how and why obstacles can manifest when attempting to transform legal norms into technical standards for the development of autonomous collision avoidance systems.

The continuously developing (hypo)thesis of the research is that COLREGS-compliance will be difficult to prove or assess from an ex-ante perspective, i.e. before the system is put into operation, for example during a certification process.

The research is also in a good position for participating in potential discussions regarding whether or not COLREGS-compliance should be a strict goal or requirement for autonomous vessels, and if so, whether one should amend the regulations to ease their safe integration.

Research approach/ methodology
The research focuses principally on analyzing case law, i.e. decisions of domestic courts, from key jurisdictions, such as the U.S and the UK, in order to clarify the legal definitions of the rules in terms of their purpose, conditions of engagement/disengagement, and the obligations they contain.

Expected results and innovations
• Determine whether the current COLREGS are wholly or partly capable of being applied to vessels with high levels of autonomy (i.e. total absence or at least very limited human involvement in the navigation process), and where possible, formulate and structure the relevant rules of the COLREGS into a format which is simpler, clearer and thus better suited for the programming of autonomous collision avoidance systems.
• Identify the gaps in legal knowledge and contribute to the development of the Law by potentially recommending amendments or changes to the current regulations.
• Potentially contribute to the development of criteria for the assessment of the compliance of autonomous vessels with the COLREGS.

Use-case involvement and industry collaboration
I will be involved mainly with Use-case no. 1 due to the interest of the industry partners in the development of autonomous navigation systems for deep-sea shipping where the vessels will be subject to the COLREGS.
Alojz Gomola, postdoc
Risk role in autonomous ship software systems

Research motivation
Addressing the issue of software safety and security in highly autonomous complex maritime system software. My research motivation is addressing the issue of software safety and security in highly autonomous complex maritime system software.

Objective and main tasks
Study the possible impact of software failures on complex transportation systems' safety and security. Elimination of probable software failures leads to increase operational safety and security.

1. Development of software failure taxonomy for a class of distributed embedded transportation systems software.
2. Design and development of risk assessment method for the software design phase to shorten development time and increase the solution's safety and security.
3. Design and development of risk validation and verification method for autonomous software systems.

Research approach/methodology
Software failure classification was done through extensive scientific literature and industrial norms and regulations. In addition, the phenomena of dynamic and static features of software failure were studied on existing autonomous transportation systems in the maritime domain provided by our industrial partners. The mechanism of software failure focused on cascading propagation through multiple hardware and software systems, including human-operator interaction, has been identified. Software failure can lead to a catastrophic chain of events and significant property and human life losses. The “Systems Theoretic Process Analysis” risk and hazard identification method is modified to cover software failure phenomena. The extension will use existing software modeling and management processes and techniques.

Expected results and innovations
Universal software failure classification - for multiple abstraction levels, platform and language independent, covers the spectrum of standard system architectures.
Software failure prevention method by safe and secure design - STPA-based method for preventive search of critical software failures coming from system and software function design.
Software failure elimination validation and verification method - STPA-based method for search of residual risk coming from unmitigated software failures in the developed software.

Use-case involvement and industry collaboration
Use case 3: Autonomous Ferries; two case studies are being executed in collaboration with industrial partners:
1. DNV ReVolt Case Study - software failure mitigation’s impact verification and validation.
2. Kongsberg Case Study - software failure prevention by design by application of STPA SW-SAF-SEC method.
Our objective is to develop the next generation cost-effective and environmentally friendly sea transport system.

Autonomous ships can dramatically change transport systems, e.g. by introducing smaller, lighter and more flexible vessels. This may be a key factor in reaching IMO's 50% goal for emission reductions by 2050 as well as other sustainable development goals. The sustainability of an autonomous ship system will depend on efficient utilization and integration of all technologies developed in the Centre. The future auto-remote solutions must be aligned with the human capabilities of any remote operators and other mariners; automated berthing and mooring, cargo handling and power supplies in port must be efficiently integrated with shipboard automation; and the combination of operational strategies, automation and transport work undertaken must be optimized to be cost-effective and environmentally sound. The introduction of autonomy will have to be done in steps and remote control and partially unmanned solutions will have to come first. The WP will investigate these steps for both physical port automation systems and navigation purposes and will provide the integration among the technologies developed in WPs 1-4 with the transport operations undertaken, and economic and environmental optimization. The WP will provide quantified evidence that the use cases developed in SFI AutoShip will be cost-effective as well as environmentally significantly better than alternatives used today.

WP5 has investigated the gaps in automation of ship cranes and cargo handling for break-bulk and containers, as well as the automated mooring systems. Conclusions from these studies show that there is several gaps when it comes to cargo handling, especially for the break-bulk segment. Remote control will be a natural first step and activities related to remote control of ship container cranes have been initiated. Automated mooring systems are already in the market, both quay-side and ship-side systems, however they are rather expensive and has not yet been taken into use by NCL and Grieg Star.

The feasibility study done as part of WP5 and WP6 has uncovered several topics to be further investigated in the work packages and the Centre. Research activities for both use case 1 and 2 have been initiated as a result of the study, with emphasis on partially unmanned bridge.
Use Case

WP Leader: Research manager Trond Johnsen, SINTEF Ocean

Our objective is to demonstrate the applicability and value-adding potential of research and innovation results from the Centre and disclose new problems for further research.

The objective of the use case is three-fold, where the use case will:
1. Provide direction and prioritization for relevant topics tied to the use case applications areas in focus
2. Be the common ground for dedicated use case workshops where the purpose is to mature requirements, needs and central technology gaps
3. Serve as an arena, through connected infrastructure, for testing and demonstrating research results and identify topics which require further research and innovation.

Each use case will involve at least one end user, product and service providers, research institutes, universities, and authorities, which represent the entire research-innovation chain as well as competence at all technology readiness levels (TRLs). At the start of the Centre, four use cases have been identified as most promising from the industry-partners’ perspective. The typical duration of the use cases will be 2-3 years with activities for each of the three use case objectives. Regarding objective 3, PhD/PD and other research activities will plan for deployment of the results in collaboration with involved partners. When the focus areas of the use case have reached a sufficiently high TRL, these will be handed over to the industry partners for further development internally and/or through new and dedicated research and innovation projects. There are currently 4 use cases.
Use Case 1: Deep-sea bulk shipping
This use case is led by the SFI partner Grieg Star. Grieg Star has defined a case scope including automation related to cargo handling and navigation, specially focusing periodically unmanned bridge during overseas sailing.

Use Case 2: Short-sea container shipping
This use case is led by SFI partner North Sea Container Line (NCL). Cargo handling is the most challenging operation today and there is a huge potential both in efficiency and safety improvement, hence also cost. This goes both for automation of the cargo handling operation itself, but also for communication between ship and terminal and other stakeholders.

Use Case 3: Ferries
This use case is led by Torghatten. This use case aims to further develop the idea of flexible and environmentally friendly passenger ferries as alternatives to bridges and the traditional ferries. The focus will be on both small urban ferries for use in cities like Trondheim, but also on bigger car ferries especially related to island connections. SFI AutoShip aims to develop and demonstrate the technology and infrastructure needed to realise new concepts for passenger ferries. Partly unmanned bridge, predictive maintenance, remote control and communication by utilizing 5G are all areas that will be investigated.

Use Case 4: Offshore support operations
This use case is led by Equinor. Research focus will be on using unmanned support vessels (USVs) in combination with autonomous underwater vehicles (AUVs) or remotely operated vehicles (ROVs) to perform inspection and maintenance operations offshore. These operations could be related to pipelines as well as floating wind installations. Equinor is already testing a first prototype which the use case will build on. Relevant research areas are communication between the assets and remote control of USV from an onshore control centre.

In 2022, research activities related to all use cases have started rolling and the first deliverables were presented at the SFI Days in October 2022. Researcher site visits onboard case vessels have been carried out for Use Case 2 and 3, and are planned for Use Case 1 and 4 early 2023. For Use Case 4, two new partners (Fugro and Reach Subsea) joined during 2022, complementing the case with vessel operator competence.
Our objective is to foster innovation culture and outcomes throughout the Centre. To facilitate innovation and ensure exploitation of research outcomes, an open mindset and mechanisms stimulating innovation will be implemented. The WP will provide new business opportunities through utilization of the research outcomes in development of new products, services, procedures, guidelines, standards, and technology.

The main activities in the work package are to ensure sound IP management in the SFI, facilitate a culture for innovation and ensure knowledge transfer between the partners. In the early phase of the SFI, the main focus has been to strengthen knowledge of innovation processes and tools through network activities between the partners and with a particular focus on the PhD/PDs. During the year the work with a utilisation plan has commenced in close cooperation with the centre innovation and commercialisation advisory committee.
Main elements of the SFI Autoship innovation strategy.
Highlights from 2022

Feasibility study

So far, both research and commercial projects have focused on autonomy for smaller ships with a certain route between specific ports and operating purely in national waters (for example Yara Birkeland and ASKO Maritime). The needs from use case 1 (NCL short-sea container ships) and 2 (Grieg Star deep-sea break-bulk ships) are different, and the question raised in these use cases is: Is this possible for a large cargo ship? This feasibility study investigated what are the biggest challenges for a fully unmanned operation of a large cargo ship internationally, without route or port restrictions. The challenges were evaluated from a technical, regulatory and commercial point of view. It was assumed that the ship can operate autonomously in most situations but may need human assistance from a remote operations center (ROC). The conclusions are based on what is feasible today, in near future and beyond.

Figure 1 shows that there are still some challenges to be solved before large cargo ships can operate unmanned. Moreover, even for a large cargo ship, some of the individual tasks can be automated today or in near future with economic, environmental, and/or social benefits. Some topics which are interesting from NCL's and Grieg Star's perspectives are: (Partially) Unmanned bridge during deep-sea phase, energy efficient navigation, and automatic mooring (safety measure).

Further work in SFI Autoship could address the following points to better accommodate unmanned ships: Safety and redundancy for power and propulsion, automatic docking (without tugboats), automated cargo handling (ship cranes), communication data between a ROC and a ship, assessment of the coming IMO MASS code and its implications, COLREGs, and a more detailed commercial assessment.

Figure 1: Technical, regulatory, and commercial feasibility
MilliAmpere 2 trial run

From late September to mid-October 2022, NTNU’s self-driving passenger ferry milliAmpere 2 had a successful trial run with passengers in the Trondheim canal, and thus became the world’s first autonomous and electric urban ferry carrying out such operations. The SFI partner Torghatten was an important partner for the trial, as well as several researchers from the Centre.

During the three-week trial operation, SFI AutoShip’s work package leader for Remote Operations Centre and Human Factors, Ole Andreas Alsos, led a survey along with researchers associated with the SFI. The survey covered not only the robustness and safety of the technology, but also how the passengers themselves experienced safety and trust in the autonomous ferry.

To study the interaction between human passengers and autonomous ships, researchers charted the passengers’ expectations before the journey, as well as their experiences afterwards.

Transporting passengers the 100 meter distance between Ravnkloa and Fosenkaia in Trondheim, milliAmpere 2 was accompanied by a ferryman row boat which was in use until the 1960s, as a symbol of the changing times.

Although NTNU personnel travelled with the passengers to answer questions and make sure they felt safe, the passengers themselves often pressed the button to start the crossing.

Crossing the canal over 400 times during the trial period, the ferry carried about 1500 people in total. Some brought their dogs and bicycles, while others came with prams and walkers, given the passenger age span of 5 months to 96 years old. Although most of the passengers tried the ferry out of curiosity, some made the crossing as part of their daily commute to work.

Researchers collected about 1000 questionnaires and carried out 150 interviews with passengers as well as skippers on boats in the channel. The experiences that the passengers
had of the ferry’s response to boat traffic was also tested, by Ole Andreas Alsos kayaking dramatically into the path of milliAmpere 2, making the ferry stop. No-one felt threatened by this, if anything they suggested the ferry responded too conservatively.

Preliminary findings suggest that most passengers felt very safe and had high levels of trust before taking the ferry, and maintained that feeling after making the crossing. Nevertheless, the passengers were initially skeptical of taking the ferry without safety personnel on board. After taking the ferry however, most were convinced of its safety even if safety personnel didn’t stay onboard.

The safety host turned out to be an important part of the passengers’ experience of trust and safety, similar to the role of elevator operators until the 1970s, when people “got used to” the technology.

Will passengers still use the ferry without personnel on board? This will be tried out in 2023, when the milliAmpere 2 will move on to an even more ambitious mission.

Photos: Kai T. Dragland/NTNU
Site visit to NCL Svelgen, Trondheim Havn in Orkanger

Researchers and PhD students visited NCL Svelgen at Trondheim Havn container terminal in Orkanger on September 21st. The information gathered will be important in the further research related to Use Case 2 - Short sea container shipping. Ship operator North Sea Container Line (NCL) crew gave a guided tour on the vessel and provided a lot of interesting information about operational experiences. The port personnel also guided around the terminal and answered questions about the port logistics.

Cargo handling is the most challenging operation for these ships today, and there is a huge potential both in efficiency and safety improvement, hence also cost. This goes both for automation of the cargo handling operation itself, but also for communication between ship and terminal and other stakeholders. Getting personnel away from cargo hold and other areas where cargo is handled is the number one challenge today, hence automated or remotely controlled cranes and equipment is of high interest. Automation of ship navigation is also a focus area in the Use Case, even if the goal is not necessarily to sail unmanned. Improved decision support and automation systems for more efficient and safer sailing is what NCL is looking for firstly. Interviewing the captain gave a better understanding of issues and factors to consider when automating navigation.

Photos: Trond Johnsen/SINTEF
Remote Control for Crane:
Postdoc Taufik Akbar Situmpol

Taufik started working as a postdoc in the SFI Autoship project in February 2022. He started his work in the project by conducting a literature review to examine different kinds of HMIs for remote crane operation that have been proposed by other researchers. The results show that there are many kinds of HMIs that have been proposed, such as overlaying virtual information onto the video stream with augmented reality, using auditory and haptic feedback as additions to visual information, and facilitating remote presence through virtual reality, just to name a few. Although not all the reviewed literature reported some sort of user evaluations, the overall results suggest that there are improvements between the conditions with and without the proposed HMIs. See publication [1] to read more about the literature review.

Taufik then conducted field studies in a container terminal, which employs both cranes still operated from the cabin and cranes operated from the remote-control room. He also interviewed eight crane operators who worked with both types of cranes to discover how both operational modes affect their work experiences. The results suggest that both operational modes positively and negatively affect the operators’ experiences. Notable positive experiences from in-cabin operation are the ability to see, feel, and respond directly and having better privacy. On the other hand, this operational mode also produces negative experiences, such as ergonomic issues and lack of social interaction. In case of remote operation, the notable positive experiences are the ability to work with high flexibility and having a more comfortable work environment. However, remote operation also produces negative experiences, such as visual fatigue and communication issue between remote operators and on-site workers. See publication [2] to read more about the field studies.

Publications referred in this text:


International Collaboration

SFI AutoShip regularly benefits from the international networks of our researchers, and Centre personnel have participated in various international conferences and workshops in 2022.

Researchers in the Centre have initiated cooperation with colleagues in several countries. Ole Andreas Alsos, our Work Package 3 leader, has collaborated on SFI-relevant papers and travelled to workshops at the Massachusetts Institute of Technology (MIT) in the US, Universidad Federal do Rio De Janeiro, Brasil, and the University of Turku, Finland during 2022. SFI personnel have also been in dialogue with researchers within maritime autonomy at the Centre for Collaborative Autonomous Systems at DTU in Denmark. Similar contact and collaboration on Explainable Artificial Intelligence (XAI) has been established with scholars at the University of Melbourne, Australia. Our researchers have also worked with colleagues at the University of Oklahoma, USA and the University of Genoa, Italy. Resulting from this, we will welcome a visiting PhD student from the latter institution during the spring semester of 2023, financed through an Erasmus project.

We have recruited the members of our Scientific Advisory Committee during 2022, of which 2 of 3 are located at institutions abroad: NATO Science and Technology Organization and School of Naval Architecture and Marine Engineering, National Technical University of Athens. The committee will begin its work in 2023.

The Centre is fortunate to have an international group of researchers, and 3 (eventually 5 in total) of our PhD candidates are part of the EU-funded PERSEUS Doctoral Programme. PERSEUS is a collaboration between NTNU and top-level academic partners in 8 countries. These candidates have been recruited internationally, and will go for research stays abroad, providing them with additional access to international networks.

Finally, the SFI has participated in international forums and projects. Centre personnel have collaborated in the EU Waterborne Technology Platform during 2022 as well, with our co-director Trond Johnsen on the board of the Zero Emission Waterborne Transport (ZWET) partnership. SFI AutoShip researchers are currently supporting the Norwegian Maritime Authority (NMA) in connection with the IMO Working Group on the ongoing development of the MASS Code. Consequently, SFI competence and networks are benefiting international institutions and processes.

Within SFI AutoShip’s Use case 3 (Ferries), Centre researchers have cooperated with key personnel from the Reboats project, a collaboration between MIT and the city of Amsterdam. We have collaborated with TU Delft in the Netherlands, through adjacent EU-funded research projects such as AutoBarge.

Odd Erik Mørkrid, our Work Package 5 leader, has continued his coordination of the EU Horizon 2020 project AEGIS, aiming to design a new waterborne logistics system. SFI AutoShip partners NCL, Trondheim Havn and MacGregor are also part of this project. In addition to AEGIS, SFI AutoShip is closely connected to the EU project AUTOSHIP with SINTEF and Kongsberg Maritime in its consortium, through the participation of several of our partners in international activities undertaken jointly by these projects. AEGIS and AUTOSHIP will finish in 2023 and the SFI will benefit from synergies and results from these projects. Going forward, Odd Erik will coordinate the EU Horizon project SEAMLESS with participation from SINTEF Ocean, NTNU, Kongsberg Maritime and MacGregor in Finland. This project will also have spill-over value for the international dimension of SFI AutoShip.
OUR TOP INTERNATIONAL RESEARCH PARTNERS

Prof. Ali Mosleh
UCLA

Prof. Andreas Molisch
University of South California

Prof. Peter Willett
University of Connecticut

Prof. Athina Petropulu
Rutgers University
## Recruitment

We recruited 4 PhDs and 2 postdocs to the Centre in 2022.

<table>
<thead>
<tr>
<th>Name</th>
<th>PhD project</th>
<th>Work package</th>
<th>Supervisor</th>
<th>Host department</th>
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<tbody>
<tr>
<td>Trym Tengesdal</td>
<td>Risk-based COLAV/anti-grounding</td>
<td>1</td>
<td>Tor Arne Johansen</td>
<td>Dept. of Engineering Cybernetics, NTNU Gløshaugen</td>
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<tr>
<td>(postdoc)</td>
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<tr>
<td>Daniel Menges</td>
<td>SITAW: The ship and its surroundings/collision</td>
<td>1</td>
<td>Adil Rasheed</td>
<td>Dept. of Engineering Cybernetics, NTNU Gløshaugen</td>
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<td>Simon Lexau</td>
<td>Docking and rendezvous for USVs</td>
<td>1</td>
<td>Anastasios Lekkas</td>
<td>Dept. of Engineering Cybernetics, NTNU Gløshaugen</td>
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<tr>
<td>Lukas Herrmann</td>
<td>Real-time ship-shore radar</td>
<td>2</td>
<td>Egil Eide</td>
<td>Dept. of Electronic Systems, NTNU Gløshaugen</td>
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<tr>
<td>Luka Grgicevic</td>
<td>Digital Twins for Autonomous Vessels</td>
<td>3</td>
<td>Ottar L. Osen</td>
<td>Dept. of ICT and Natural Sciences, NTNU Ålesund</td>
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<tr>
<td>Taufik Akbar Sitompul</td>
<td>Remote Control for Crane</td>
<td>3</td>
<td>Ole Andreas Alsos</td>
<td>Dept. of Design, NTNU Nyhavna</td>
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<tr>
<td>(postdoc)</td>
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</table>
Centre researchers and PhDs visiting the ferry connecting Ytterøy to Levanger, in March 2022, to consider and learn about possibilities for autonomy. They met with the shipping company and 3 captains who contributed with valuable knowledge and experience. Photos: Trond Johnsen/ SINTEF

PhD/postdoc colloquium in June 2022. Photo: Raffael Wallner/NTNU
PhDs and Postdocs

Melih Akdağ
Collaborative Collision Avoidance for Autonomous Ships
Supervisors: Tor Arne Johansen and Thor I. Fossen (ITK, NTNU)

Luka Grgicevic
Digital Twins for Autonomous Vessels
Supervisors: Ottar L. Osen and Robin T. Bye (IIR, NTNU), Thor I. Fossen (ITK, NTNU)

Spencer A. Dugan
Reliable design and operation of propulsion systems for autonomous ships
Supervisors: Ingrid B. Utne and Mehdi Zadeh (IMT, NTNU)

Lukas Herrmann
Real-time ship-shore radar
Supervisors: Egil Eide and Edmund Brekke (ITK, NTNU)

Eirik Fagerhaug
Explainable AI for Autonomous Ships
Supervisors: Ottar L. Osen and Robin T. Bye (IIR, NTNU), Anastasios Lekkas (ITK, NTNU)

Susanna Dybwad Kristensen
Online risk modelling of autonomous ships
Supervisors: Ingrid B. Utne and Astrid H. Brodtkorb (IMT, NTNU)

Henrik Dobbe Flemmen
Simultaneous localization and mapping (SLAM) for autonomous ships
Supervisors: Edmund Brekke, Kostas Alexis, Anette Stahl and Torleiv Bryne (ITK, NTNU), Rudolf Mester (IDI, NTNU)

Simon Lexau
Docking and rendezvous for USVs
Supervisors: Anastasios Lekkas and Morten Breivik (ITK, NTNU)

Alojz Gomola
Risk role in autonomous ship software systems
Supervisor: Ingrid Bower Utne (IMT, NTNU)

Andreas Nygard Madsen
AI decision transparency in autonomous shipping
Supervisors: Magne Aarset (IHB, NTNU), Ole Andreas Alsos (Dept. of Design, NTNU), Tae-Eun Kim (UiT)
Emil Martens  
Multi sensor detection for autonomous surface vehicles  
Supervisors: Annette Stahl and Edmund Førland Brekke (ITK, NTNU), Rudolf Mester (IDI, NTNU)

Trym Tengesdal  
Risk-based COLAV/anti-grounding  
Supervisor: Tor Arne Johansen (ITK, NTNU)

Daniel Menges  
SITAW: The ship and its surroundings/collision avoidance  
Supervisors: Adil Rasheed, Edmund Brekke and Anastasios Lekkas (ITK, NTNU)

Raffael Wallner  
Safety Demonstration of Autonomously Controlled Ships using Digital Twin  
Supervisors: Mary Ann Lundteigen and Tor Arne Johansen (ITK, NTNU), Bjørn Axel Gran (IFE), Tom Arne Pedersen (DNV)

Felix-Marcel Petermann  
Interaction Design for Autonomous Ships  
Supervisors: Ole Andreas Alsos and Eleftherios Papachristos (Dept. of Design, NTNU)

Taufik Akbar Sitompul  
Remote Control for Crane  
Supervisor: Ole Andreas Alsos (Dept. of Design, NTNU)

Ayoub Tailoussane  
The application of the COLREGs to autonomous vessels, and the challenge of translating legal concepts into machine comprehensible data for the development of COLREGs-compliant autonomous vessels  
Supervisors: Trond Solvang (NIFS, UiO), Dag Wiese Schartum (IFP, UiO)
News coverage in 2022

MilliAmpere 2 trial operation

MilliAmpere II, the world’s first urban autonomous passenger ferry, had its first trial run with passengers with WP 3 involvement in the trial. The event was widely covered by national, regional and sector specific media (such as TV2, Dagbladet, Adresseavisen, Universitetsavisa, Gemini, Teknisk Ukeblad, forskning.no) and international media (among others Evening Standard, Safety4Sea, Baird Maritime, Computerworld Switzerland, Computer Hoy).

From top left: Gemini, Evening Standard (UK), Universitetsavisa, Dagbladet, Adresseavisen, Computerworld Switzerland.
Reach Subsea joins SFI AutoShip

The Haugesund-based company Reach Subsea entered the consortium in 2022, and their work on remote and autonomous operations of subsea vessels and involvement in the Centre was subsequently covered in Haugesunds Avis.


Norsk selvkjørende ferje skal frakte folk omtrent som i en heis

Reach Subsea is an operating company within the consortium with responsibility for the project. Their involvement in the Centre was covered in Forskning.no on 18.05.2022.

Forskning.no, «Norsk selvkjørende ferje skal frakte folk omtrent som i en heis», 18.05.2022.
Events

Visit from the Minister of Trade and Industry. Minister of Trade and Industry Jan Christian Vestre visited Nyhavna in May to meet representatives from the Ocean Autonomy Cluster, Smart Mobility Norway and SFI AutoShip. Photo: Birgit Thorsen/Fremtids Industrin

Presenting the SFI to the Norwegian Association for Autonomous Ships. Mary Ann Lundteigen presenting the SFI at a NFAS seminar in June. Photo: Marius Tvinneheim/Fremtids Industrin
SFI Days

The SFI AutoShip Days of 2022 were held in Trondheim on 25-26 October. We were delighted to welcome over 80 participants from our industry partners, public sector partners and research partners. We enjoyed stimulating presentations and discussions, and this year’s gathering had a strong focus on industry use cases. All use cases (1-4) were showcased on the first day, with presentations from Equinor, Fugro, Reach Subsea, Grieg Star and SINTEF. We heard from both new and soon to be finished PhDs and postdocs, received a status of the research output from the Centre so far, and a look at the development of the dissemination and utilization plan. On the second day an NTNU team shared insights from the trial operation of the world’s first autonomous passenger ferry, milliAmpere 2. We then heard about the regulatory aspects of Maritime Autonomous Surface Ships (MASS) from the NMA and DNV, while Kongsberg Maritime closed the day with the current status and possible scale-up of ongoing MASS projects.
SFI AutoShip Researcher Workshops

We held researcher workshops in March and September, with a joint session in the morning and parallel sessions divided by work packages in the afternoon. The images below are from the September workshop.
## Publications and Presentations in 2022

<table>
<thead>
<tr>
<th>Type</th>
<th>Name/description</th>
<th>Name of journal/conference/book</th>
<th>Main author</th>
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<tbody>
<tr>
<td><strong>Journal articles</strong></td>
<td>Collaborative Collision Avoidance for Autonomous Ships Using Informed Scenario-Based Model Predictive Control</td>
<td>IFAC-PapersOnLine</td>
<td>Melih Akdag, Thor I. Fossen and Tor Arne Johansen</td>
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<tr>
<td></td>
<td>Collaborative collision avoidance for Maritime Autonomous Surface Ships: A review</td>
<td>Ocean Engineering</td>
<td>Melih Akdag, Petter Solnør and Tor Arne Johansen</td>
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<tr>
<td></td>
<td>Safe and efficient maneuvering of a Maritime Autonomous Surface Ship (MASS) during encounters at sea: A novel approach</td>
<td>Maritime Transport Research</td>
<td>Andreas Madsen, Magne Aarset and Ole Andreas Alsos</td>
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<td></td>
<td>Online wave direction and wave number estimation from surface vessel motions using distributed inertial measurement arrays and phase-time-path-differences</td>
<td>Ocean Engineering</td>
<td>Johann Alexander Dirdal, Roger Skjetne, Jan Roháč, Thor I. Fossen</td>
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<td>Heterogeneous multi-sensor tracking for an autonomous surface vehicle in a littoral environment</td>
<td>Ocean Engineering</td>
<td>Øystein Karstad Helgesen, Kjetil Vasstein, Edmund Farland Brekke, Annette Stahl</td>
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<td>A Rudimentary Mission Planning System for Marine Autonomous Surface Ships</td>
<td>IFAC-PapersOnLine</td>
<td>Miguel Hinostroza and Anastasios M. Lekkas</td>
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<tr>
<td></td>
<td>Reinforcement learning-based NMPC for tracking control of ASVs: Theory and experiments</td>
<td>Control Engineering Practice</td>
<td>Andreas Bell Martinsen, Anastasios M. Lekkas and Sebastien Gros</td>
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<tr>
<td>Programming “The ordinary practice of seamen” into the AI-navigator: friendly and communicative interaction design between autonomous and manned vessels</td>
<td>Necessse</td>
<td>Thomas Porathe</td>
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<tr>
<td>Human–Machine Interface for Remote Crane Operation: A Review</td>
<td>Multimodal Technologies and Interaction</td>
<td>Taufik Akbar Sitompul</td>
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<tr>
<td>Ship Collision Avoidance and Anti Grounding Using Parallelized Cost Evaluation in Probabilistic Scenario-Based Model Predictive Control</td>
<td>IEEE Access</td>
<td>Trym Tengesdal, Tor Arne Johansen, Tom Daniel Grande and Simon André Johnsen Blindheim</td>
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<tr>
<td>Static obstacle avoidance and docking of ASVs using computational geometry and numerical optimal control</td>
<td>IFAC-PapersOnLine</td>
<td>Petter K. Ødven, Andreas Bell Martinsen and Anastasios M. Lekkas</td>
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<tr>
<td>Conference papers/Workshop presentations</td>
<td>Collaborative Collision Avoidance for Autonomous Ships Using Informed Scenario-Based Model Predictive Control</td>
<td>14th IFAC Conference on Control Applications in Marine Systems</td>
<td>Melih Akdag, Thor I. Fossen and Tor Arne Johansen</td>
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<tr>
<td>milliAmpere2 and NTNU Shore Control Lab</td>
<td>International Seminar with TaiTech, Estonia</td>
<td>Ole Andreas Alsos</td>
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<tr>
<td>Presentation of MIDAS, NTNU Shore Control Lab, and milliAmpere2</td>
<td>MIT Media Lab, USA</td>
<td>Ole Andreas Alsos</td>
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<tr>
<td>Presentation of MIDAS, NTNU Shore Control Lab, and milliAmpere2</td>
<td>Universidad Federal do Rio De Janeiro, Brasil</td>
<td>Ole Andreas Alsos</td>
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<tr>
<td>Hypothesis Exploration in Multiple Hypothesis Tracking with Multiple Clusters</td>
<td>25th International Conference on Information Fusion - FUSION</td>
<td>Edmund Førland Brekke and Lars-Christian Ness Tokle</td>
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<tr>
<td>STPA-based hazard analysis of a ship collision avoidance and stability monitoring system</td>
<td>10th European STAMP Workshop and Conference</td>
<td>Spencer A. Dugan, Ingrid B. Utne, Roger Skjetne, Jakub Montewka, Mateusz Gil and Krzysztof Wrobel</td>
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<tr>
<td>Unsupervised Clustering of Marine Vessel Trajectories in Historical AIS Database</td>
<td>25th International Conference on Information Fusion - FUSION</td>
<td>Ravinder Praveen Kumar Jain, Edmund Førland Brekke and Adil Rasheed</td>
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<tr>
<td>Prediction and evaluation of an angle of heel due to turning maneuver of small training ships: comparison of dynamic analysis and static design criteria</td>
<td>Proceedings of the 15th International Symposium on Practical Design of Ships and Other Floating Structures (PRADS 2022, University of Zagreb)</td>
<td>Przemyslaw Krata, Tomasz Hinz, Spencer A. Dugan, Mathias H. Marley and Jakub Montewka</td>
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<tr>
<td>Title</td>
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<td>Authors/Contributors</td>
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<td>DSA-inspired assessment of autonomous ships stability during turning maneuver</td>
<td>Proceedings of the 18th International Ship Stability Workshop (Gdansk University of Technology)</td>
<td>Przemyslaw Krata, Tomasz Hinz, Mathias H. Marley, Spencer A. Dugan, Mateusz Gil, Jakub Montewka and Roger Skjetne</td>
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<td>Dynamic Risk Analysis of Maritime Autonomous Surface Ships</td>
<td>Probabilistic Safety Assessment and Management PSAM 16</td>
<td>Susanna Dybwad Kristensen, Yiliu Liu and Ingrid Bouwer Utne</td>
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<td>Safety and Assurance of Autonomous Ships: Framing of Research Actions</td>
<td>MTEC/ICMASS 2022</td>
<td>Mary Ann Lundteigen and Ingrid Bouwer Utne</td>
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<td>When do meeting ships of a MASS deviate from COLREG?</td>
<td>Fjordkonferansen 2022</td>
<td>Andreas Solnordal Madsen</td>
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<td>Increasing the Usability of Audio Alerts with Voice Instructions on Ship's Bridges</td>
<td>Human Factors in Accessibility and Assistive Technology. AHFE (2022) International Conference</td>
<td>Felix-Marcel Petermann, Malene Liavaag, Julie Karine Schmidt Solberg, Ole Andreas Alsos and Erik Styhr Petersen</td>
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<td>Collision Avoidance for autonomous ships (MASS): making assumptions about other ships intended routes.</td>
<td>Proceedings of the 32nd European Safety and Reliability Conference (ESREL 2022)</td>
<td>Thomas Porathe</td>
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<td>Where does the pilot go when the autonomous ship has no bridge? MASS Routing Service and smart Local Information Centres</td>
<td>Proceedings of the Autonomous Ship Conference 2022</td>
<td>Thomas Porathe</td>
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<td>Keynote: Robotics and vision-based autonomic systems in challenging environments</td>
<td>2022 EIROforum Topical Workshop on Robotics &amp; Remote Operation</td>
<td>Annette Stahl</td>
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<td>Seeing the Unseen: Visual Perception for Autonomous Robots</td>
<td>AMOS Days</td>
<td>Annette Stahl</td>
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<td>Collision Avoidance Rules and their application to Autonomous Vessels</td>
<td>Presentation at the Arctic University of Norway (UiT)</td>
<td>Ayoub Tailoussane</td>
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<td>Collision Avoidance Rules and their application to Autonomous Vessels</td>
<td>Nordisk Sjørettsseminar 2022</td>
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<td>Compliance with the ColRegs and predictable navigation – Some legal challenges</td>
<td>SFI AutoShip webinar on regulatory challenges and possibilities for unmanned ships</td>
<td>Ayoub Tailoussane</td>
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<td>Joint Stochastic Prediction of Vessel Kinematics and Destination based on a Maritime Traffic Graph</td>
<td>IEEE 2022 3rd International Conference on Electrical, Computer, Communications and Mechatronics Engineering (ICECCME)</td>
<td>Trym Tengesdal, Leonardo M. Millefiori, Paolo Braca and Edmund Førland Brekke</td>
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<td>Approaches to Utilize Digital Twins in Safety Demonstration and Verification of Automated and Autonomously Controlled Systems.</td>
<td>Proceedings of the 32nd European Safety and Reliability Conference (ESREL 2022).</td>
<td>Raffael Andrea Wallner and Mary Ann Lundteigen</td>
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<td>Reports</td>
<td>SINTEF report</td>
<td>Pauline Røstum Bellingmo and Ulrik Jørgensen</td>
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<td>Other presentations and selected events</td>
<td>Avanserte Fartøyer 2022</td>
<td>Ole Andreas Alsos</td>
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<td>Invited keynote: Man in future maritime operations</td>
<td>Ship Technology Days</td>
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<td>Invited talk: When the captain goes ashore</td>
<td>Ocean Autonomy Conference</td>
<td>Ole Andreas Alsos</td>
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<td>Keynote: How to design for trust</td>
<td>Industrial Design Conference 2022</td>
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<td>Keynote: Human factors in the age of autonomous systems</td>
<td>Nordic Ergonomics and Human Factors Society Conference 2022 (NES)</td>
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<td>milliAmpere2 trial og fjernoperasjon</td>
<td>Sjøfartsdirektoratet Ny-teknologi samling</td>
<td>Ole Andreas Alsos</td>
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<td>Mulighetene som autonome operasjoner gir til videreutvikling av kystnært havbruk</td>
<td>Brohodekonferansen 2022</td>
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<td>Presentasjon av milliAmpere2 og Shore Control Lab</td>
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<td>Presentation and demonstration of milliAmpere2</td>
<td>Opening milliAmpere2</td>
<td>Ole Andreas Alsos</td>
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<td>Presentation of milliAmpere2 and Shore Control Lab</td>
<td>NTNU Researchers’ Night</td>
<td>Ole Andreas Alsos</td>
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<td>Presentation of SFI Autoship and the milliAmpere2 trial</td>
<td>SMASH, Nederlands Forum Smart Shipping</td>
<td>Ole Andreas Alsos</td>
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<td>Presentation of the Shore Control Lab, milliAmpere2</td>
<td>Media visit by Leon Kirchen, Süddetuche Zeitung</td>
<td>Ole Andreas Alsos</td>
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<td>Prøvedrift av verdens første autonome byferge</td>
<td>Norsk forum for autonome skip (NFAS) Årsmøte</td>
<td>Ole Andreas Alsos</td>
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<td>Presentation of NTNU Shore Control Lab</td>
<td>Visit from Minister of Trade and Industry and Trondheim Major</td>
<td>Ole Andreas Alsos</td>
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<tr>
<td>Exhibition of NTNU Shore Control Lab and MilliAmpere 2</td>
<td>Ocean Week 2022 - An Ocean of Knowledge</td>
<td>Ole Andreas Alsos and Felix-Marcel Petermann</td>
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<td>Presentation of Shore Control Lab</td>
<td>Visit from Norwegian Minister of Fisheries and Ocean Politics</td>
<td>Ole Andreas Alsos and Felix-Marcel Petermann</td>
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<tr>
<td>Norsk selvkjørende ferje skal frakte folk omtrent som i en heis.</td>
<td>Forskning.no</td>
<td>Bjørn Lønnum Andreassen, Ole Andreas Alsos, Morten Breivik and Egil Eide</td>
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<tr>
<td>SFI AutoShip - An Introduction</td>
<td>Norwegian Maritime Authority Workshop</td>
<td>Anastasios M. Lekkas</td>
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<tr>
<td>SFI AutoShip - An Introduction</td>
<td>SMASH! visit to Norway</td>
<td>Anastasios M. Lekkas</td>
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<tr>
<td>Maritime Data Space: Trygg og effektiv informasjonsutveksling.</td>
<td>Haugesundkonferansen 2022</td>
<td>Dag Atle Nesheim</td>
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<td>From humans to machines – Autonomous Vessels and the application of the COLREGs.</td>
<td>Presentation at the Norwegian Maritime Authority</td>
<td>Ayoub Tailoussane</td>
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# Master Students 2022

## Master Students Obtaining Their Degree on an SFI Autoship Topic in 2022

<table>
<thead>
<tr>
<th>Name</th>
<th>Sex</th>
<th>Thesis Title</th>
<th>Supervisors</th>
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<tbody>
<tr>
<td>Karine Borgerud</td>
<td>F</td>
<td>Combined Safety and Security Analysis on an Autonomous Passenger Ferry Using CyPHASS</td>
<td>Mary Ann Lundteigen</td>
</tr>
<tr>
<td>Bjørn Theodor Torp Brørby</td>
<td>M</td>
<td>Wave load compensation in DP control systems</td>
<td>Roger Skjetne, Mathias Marley</td>
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<tr>
<td>Hilmar Nypan Claes; Malene Liavaag; Vedran Simic</td>
<td>M,F,M</td>
<td>Design an autonomous passenger ferry for urban areas</td>
<td>Ole Andreas Alsos, Leander Spyridon Pantelatos</td>
</tr>
<tr>
<td>Markus Engøy Duna</td>
<td>M</td>
<td>Oppfatninger i eldre nordisk og utenlandsk teori om skyldvilkåret som betingelse for rederens prinsipalansvar ved skipssammenstøt – med henblikk på autonome skip</td>
<td>Trond Solvang</td>
</tr>
<tr>
<td>Sondre Ek</td>
<td>M</td>
<td>Design of simulator for researching autonomous marine vessels</td>
<td>Ole Andreas Alsos</td>
</tr>
<tr>
<td>Martin Falang</td>
<td>M</td>
<td>Autonomous UAV Landing on a Boat - Perception, Control and Mission Planning</td>
<td>Anastasios Lekkas</td>
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<tr>
<td>Mikal Røsbak Hanssen</td>
<td>M</td>
<td>Developing a video game for research and prototyping of unmanned maritime vessels</td>
<td>Yngve Dahl, Ole Andreas Alsos, Erik Veitch</td>
</tr>
<tr>
<td>Erlend Hestvik</td>
<td>M</td>
<td>COLREGs-aware and MPC-based trajectory planning and collision avoidance for autonomous surface vessels</td>
<td>Morten Breivik, Emil Thyri</td>
</tr>
<tr>
<td>Philip Hodne; Oskar Kristoffer Skåden</td>
<td>M,M</td>
<td>Automation Transparency For Maritime Autonomous Surface Ships Through Conversational User Interfaces</td>
<td>Ole Andreas Alsos, Thomas Pørath</td>
</tr>
<tr>
<td>Ola Johan Olimb Kirkerud</td>
<td>M</td>
<td>COLREGs-Aware Collision Avoidance for Autonomous Surface Vehicles using Encounter-Specific Artificial Potential Fields</td>
<td>Morten Breivik, Emil Thyri</td>
</tr>
<tr>
<td>Karen Solem Knutsen</td>
<td>F</td>
<td>Analysis of AIS data for COLREGS compliance</td>
<td>Tor Arne Johansen</td>
</tr>
<tr>
<td>Amalie Kolsgaard</td>
<td>F</td>
<td>Improved Maritime Vessel Detection in Camera Images using Bag-of-Visual-Words</td>
<td>Annette Stahl, Edmund Brekke, Rudolf Mester</td>
</tr>
<tr>
<td>Helene Mjøs</td>
<td>F</td>
<td>Overvåkning av tilstand og sikkerhet for ubemannede skip - Hvordan sikre felles situasjonsforståelse mellom skip og operasjonssenteret.</td>
<td>Thor Hukkelås, Øystein Andreassen</td>
</tr>
<tr>
<td>Martin Navarsete Murvold</td>
<td>M</td>
<td>Evaluation of COLREGs compliance, when considering grounding hazards</td>
<td>Tor Arne Johansen</td>
</tr>
<tr>
<td>Jooyoung Park</td>
<td>F</td>
<td>Graphical User Interface Design for a Remote Operator to Monitor and Control Multiple Autonomous Ferries</td>
<td>Ole Andreas Alsos, Øyvind Smogeli</td>
</tr>
<tr>
<td>Elias Strømmen Ravnestad</td>
<td>M</td>
<td>Time-domain wave estimation and prediction using wave radar on R/V Gunnerus</td>
<td>Roger Skjetne, Mathias Marley</td>
</tr>
<tr>
<td>Vegard Sanden</td>
<td>M</td>
<td>High-level Action Planning for Marine Vessels Using Active Inference and Reinforcement Learning</td>
<td>Anastasios Lekkas</td>
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<tr>
<td>Julie Karine Schmidt Solberg</td>
<td>F</td>
<td>Design of additional radar features to improve the usability of radar tuning</td>
<td>Erik Styhr Petersen, Ole Andreas Alsos</td>
</tr>
<tr>
<td>Mathias Solheim</td>
<td>M</td>
<td>Integration between lidar- and camera-based situational awareness and control barrier functions for an autonomous surface vehicle</td>
<td>Roger Skjetne, Mathias Marley</td>
</tr>
<tr>
<td>Sara Emilie Thode</td>
<td>F</td>
<td>Shared Situation Awareness in Maritime Navigation</td>
<td>Thor Hukkelås, Øystein Andreassen</td>
</tr>
<tr>
<td>Joachim Ullmann Miller</td>
<td>M</td>
<td>Automation transparency in the maritime domain. How autonomous ships can use external human-machine interfaces to communicate with their surroundings</td>
<td>Tor Arne Johansen</td>
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<tr>
<td>Olav Buset Vassbotn</td>
<td>M</td>
<td>Analysis of ship collision risk encounters and COLREG behaviours using machine learning and AIS data</td>
<td>Tor Arne Johansen</td>
</tr>
<tr>
<td>Petter K. Ødven</td>
<td>M</td>
<td>Static and dynamic multi-obstacle avoidance for docking of ASVs using computational geometry and numerical optimal control</td>
<td>Anastasios Lekkas</td>
</tr>
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## Annual Accounts for 2022

All figures in 1000 NOK.

### FUNDING

<table>
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<tr>
<td>The Research Council</td>
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<td>Research Partners*</td>
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<td>Enterprise partners**</td>
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<td>Public partners***</td>
<td>29</td>
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### COSTS

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<tr>
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<tr>
<td>Enterprise partners**</td>
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<td>Public partners***</td>
<td>29</td>
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<tr>
<td><strong>Total</strong></td>
<td><strong>32 112</strong></td>
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</table>

*Research Partners*

- Universitet i Oslo
- SINTEF AS
- SINTEF Ocean AS
- Institutt for energiteknikk

*Enterprise Partners*

- DNV AS
- Embron Group AS
- Equinor Energy AS
- Fugro Norway AS
- G2 Ocean AS
- Gard AS
- Grieg Star AS
- Idletechs AS
- Kongsberg Maritime AS
- MacGregor Norway AS
- Maritime Robotics AS
- Massterly AS
- North Sea Container Line AS
- Reach Subsea AS
- Telia Norge AS
- Torghatten ASA

*Public Partners*

- Sjøfartsdirektoratet
- Kystverket
- Trondheim kommune
- Trondheim Havn IKS

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Annual Report 2022
# Key Personnel

**CENTRE MANAGEMENT AND ADMINISTRATION**

- Anastasios Lekkas  
  Centre Director
- Ingrid Bouwer Utne  
  Centre co-director
- Trond Johnsen  
  Centre co-director
- Kjell Olav Skjølsvik  
  Innovation Manager
- Ingeborg Guldal  
  Administrative Coordinator
- Steve Løkkeberg Harila  
  Financial Adviser

**KEY RESEARCHERS**

- **Adil Rasheed**  
  Dept. of Engineering Cybernetics  
  Big data cybernetics, hybrid analysis and modelling
- **Anastasios Lekkas**  
  Dept. of Engineering Cybernetics Autonomous systems  
  Autonomous systems
- **Annette Stahl**  
  Dept. of Engineering Cybernetics Autonomous systems  
  Sensor fusion
- **Edmund Brekke**  
  Dept. of Engineering Cybernetics  
  Robotics systems
- **Egil Eide**  
  Dept. of Electronic Systems  
  Sensors fusion
- **Einar Hareide**  
  Dept. of Design  
  Industrial design
- **Ingrid Bouwer Utne**  
  Dept. of Marine Technology  
  Operational risk in marine and maritime systems
- **Kimmo Kansanen**  
  Dept. of Electronic Systems  
  Signal processing
- **Kjell Olav Skjølsvik**  
  Dept. of Marine Technology  
  Innovation Manager
- **Magne Aarset**  
  Dept. of Ocean Operations and Civil Engineering  
  Risk Management/ Artificial intelligence
- **Mary Ann Lundteigen**  
  Dept. of Engineering Cybernetics  
  Safety, reliability and automation systems
- **Morten Breivik**  
  Dept. of Engineering Cybernetics  
  Autonomous systems
- **Ole Andreas Alsos**  
  Dept. of Design  
  Interaction design
- **Ottar L. Osen**  
  Dept. of ICT and Natural Sciences  
  Cybernetics and artificial intelligence
- **Pierluigi Salvo Rossi**  
  Dept. of Electronic Systems  
  Explained AI, automation transparency
- **Robin Bye**  
  Dept. of ICT and Natural Sciences  
  Explained AI, automation transparency
- **Roger Skjetne**  
  Dept. of Marine Technology  
  Marine cybernetics
- **Runar Ostnes**  
  Dept. of Ocean Operations and Civil Engineering  
  Nautical science, navigation systems and nautical operations
- **Thomas Porathe (retired)**  
  Dept. of Design  
  Human factors and remote control centres
- **Thor I. Fossen**  
  Dept. of Engineering Cybernetics  
  Cyber security, navigation and control of marine craft
- **Tor Arne Johansen**  
  Dept. of Engineering Cybernetics  
  Automatic control
- **Torbjørn Ekman**  
  Dept. of Electronic Systems  
  Radio communications, communication theory and signal processing
KEY RESEARCHERS

UNIVERSITY OF OSLO (UIO)

Trond Solvang
UiO, Scandinavian Institute of Maritime Law

MAIN RESEARCH AREA

Maritime law, torts law, contract law

KEY RESEARCHERS

SINTEF

Dag Atle Nesheim
SINTEF Ocean
Energy and transport

Eirik Flemsæter Falck
SINTEF Digital
Detection, tracking, crane control

Espen Tangstad
SINTEF Ocean
Autonomous control system design

Esten Ingar Grøtli
SINTEF Digital
Sensor fusion, estimation, path planning

Håvard Nordahl
SINTEF Ocean
Autonomous ships and maritime transport

Johannes Tjønnås
SINTEF Digital
Cargo handling, control systems

Marianna Vagia
SINTEF Digital
Autonomy, risk assessment, path planning, control algorithms

Mariann Merz
SINTEF Digital
Maritime logistics and autonomous shipping

Odd Erik Mørkrid
SINTEF Ocean
Maritime digitalization, autonomous shipping

Pauline Røstum Bellingmo
SINTEF Ocean
Maritime transport and logistics

Trond Johnsen
SINTEF Ocean
Autonomous maritime systems and simulations

Ulrik Jørgensen
SINTEF Ocean
Maritime digitalization, autonomous control system design

Ørnulf Jan Rødseth
SINTEF Ocean

KEY RESEARCHERS

IFE

Bjørn Axel Gran
Research director
Risk, safety and security

Linda Sofie Lunde-Hanssen
Senior Scientist
Control room and interaction design

Stine Aurora Mikkelsplass
Junior Scientist
Safety, risk and security

Stine Strand
Research director
Control room and interaction design
## Temporary and Affiliated Personnel

### POSTDOCTORAL RESEARCHERS WITH FINANCIAL SUPPORT FROM THE CENTRE BUDGET

<table>
<thead>
<tr>
<th>NAME</th>
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<th>NATIONALITY</th>
<th>PERIOD</th>
<th>TOPIC</th>
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<tbody>
<tr>
<td>Alojz Gomola</td>
<td>M</td>
<td>Slovakian</td>
<td>12.07.2021-11.07.2023</td>
<td>Dynamic and simulation-based risk modeling for operational decision support and verification</td>
</tr>
<tr>
<td>Taufik Akbar Sitompul</td>
<td>M</td>
<td>Indonesian</td>
<td>01.02.2022-01.02.2024</td>
<td>Remote Control for Crane/ Design of human-machine interface</td>
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### POSTDOCTORAL RESEARCHERS WORKING ON PROJECTS IN THE CENTRE WITH FINANCIAL SUPPORT FROM OTHER SOURCES

<table>
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<th>PERIOD</th>
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<tr>
<td>Praveen Jain</td>
<td>M</td>
<td>Indian</td>
<td>01.05.2022-01.09.2023</td>
<td>Long-term vessel prediction</td>
<td>Autosit/ MAROFF/NFR</td>
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### PHD STUDENTS WITH FINANCIAL SUPPORT FROM THE CENTRE BUDGET

<table>
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<th>PERIOD</th>
<th>TOPIC</th>
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<tbody>
<tr>
<td>Melih Akdag</td>
<td>M</td>
<td>Turkish</td>
<td>20.05.2021-19.05.2024</td>
<td>Collaborative collision avoidance for autonomous ships</td>
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<tr>
<td>Susanna Dybwad Kristensen</td>
<td>F</td>
<td>Norwegian</td>
<td>16.08.2021-15.07.2024</td>
<td>Online risk modeling of autonomous ships</td>
</tr>
<tr>
<td>Henrik Dobbe Flemmen</td>
<td>M</td>
<td>Norwegian</td>
<td>01.10.2021-30.09.2024</td>
<td>Non-GNSS localization for USVs (aka SLAM)</td>
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<tr>
<td>Emil Martens</td>
<td>M</td>
<td>Norwegian</td>
<td>11.08.2021-11.08.2026</td>
<td>Multi-sensor object detection and classification</td>
</tr>
<tr>
<td>Felix Peterman</td>
<td>M</td>
<td>German</td>
<td>01.08.2021-31.07.2025</td>
<td>Interaction Design</td>
</tr>
<tr>
<td>Andreas Nygard Madsen</td>
<td>M</td>
<td>Norwegian</td>
<td>01.09.2021-31.07.2024</td>
<td>Explainable AI for autonomous maritime operations</td>
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<tr>
<td>Eirik Fagerhaug</td>
<td>M</td>
<td>Norwegian</td>
<td>16.08.2021-15.08.2024</td>
<td>Risk acceptance and operational constraints in risk modeling of autonomous operations.</td>
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<tr>
<td>Spencer Dugan</td>
<td>M</td>
<td>American</td>
<td>01.09.2021-31.08.2024</td>
<td>Risk acceptance and operational constraints in risk modeling of autonomous operations.</td>
</tr>
<tr>
<td>Ayoub Tailoussane</td>
<td>M</td>
<td>Moroccan</td>
<td>01.09.2021-31.08.2024</td>
<td>COLREGS and their connection with autonomous vessels</td>
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<tr>
<td>Raffael Wallner</td>
<td>M</td>
<td>Austrian</td>
<td>28.11.2021-27.11.2024</td>
<td>Safety demonstration of autonomous control systems using digital twin</td>
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<tr>
<td>Simon Lexau</td>
<td>M</td>
<td>Norwegian</td>
<td>23.08.2022-22.08.2025</td>
<td>Docking and rendezvous for USVs</td>
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<tr>
<td>Lukas Herrmann</td>
<td>M</td>
<td>German</td>
<td>01.06.2022-31.05.2025</td>
<td>Real-time ship-shore radar</td>
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<tr>
<td>Daniel Menges</td>
<td>M</td>
<td>German</td>
<td>17.01.2022-16.01.2025</td>
<td>SITAW: The ship and its surroundings/collision avoidance</td>
</tr>
<tr>
<td>Luka Grgicevic</td>
<td>M</td>
<td>Croatian</td>
<td>31.01.2022-30.01.2025</td>
<td>Decision Support Systems for Autonomous Vessens</td>
</tr>
<tr>
<td>NAME</td>
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<tr>
<td>Audun Hem</td>
<td>M</td>
<td>Norwegian</td>
<td>01.10.2020-30.11.2023</td>
<td>PhD in the Autosit project: Autonomous ships, intentions and situational awareness</td>
</tr>
<tr>
<td>Øystein Helgesen</td>
<td>M</td>
<td>Norwegian</td>
<td>01.08.2022-31.07.2023</td>
<td>Sensor Fusion and Situational Awareness for autonomous urban ferries in the Autoferry project. Research topics include perception, sensor fusion and target tracking.</td>
</tr>
<tr>
<td>Lars-Christian Tokle</td>
<td>M</td>
<td>Norwegian</td>
<td>01.01.2019-01.03.2024</td>
<td>Sensor Fusion and Situational Awareness for autonomous urban ferries in the Autoferry project. Research topics include sensor fusion for SLAM and target tracking.</td>
</tr>
<tr>
<td>Inger Berge Hagen</td>
<td>F</td>
<td>Norwegian</td>
<td>01.01.2020-31.12.2022</td>
<td>Maritime Collision Avoidance</td>
</tr>
<tr>
<td>Johan Bakken Sørensen</td>
<td>M</td>
<td>Norwegian</td>
<td>01.08.2022-31.07.2025</td>
<td>Safety and assurance of autonomous ships</td>
</tr>
<tr>
<td>Erik Veitch</td>
<td>M</td>
<td>Finnish</td>
<td>01.10.2020-01.07.2023</td>
<td>Human-AI interaction in highly automated ships. How can we safely operate autonomous ships?</td>
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</table>