ANNUAL REPORT 2022

SFI· AUTOSHIP

Autonomous ships for safe and sustainable operations

Norwegian Centre for Research-based Innovation

SFI· AUTOSHIP

NTNU Norwegian University of Science and Technology

FUNDING AGENCY

The Research Council of Norway

RESEARCH PARTNERS

SINTEF

IFE

UiO

INDUSTRY PARTNERS

MARITIME ROBOTICS

idletechs

equinor

DNV

G2 OCEAN

FUGRO

GRIEG STAR

EMBRON

massterly a Kongsberg Wilhelmsen joint venture

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REACH SUBSEA

Telia

KONGSBERG

NCL North Sea Container Line

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PUBLIC AND GOVERNMENTAL PARTNERS

Sjøfartsdirektoratet Norwegian Maritime Authority

Trondheim Havn

TRONDHEIM KOMMUNE

KYSTVERKET

HOST

NTNU

Faculty of Information Technology
and Electrical Engineering
Department of Engineering Cybernetics

Grafisk design og produksjon: NTNU Grafisk senter

CONTENTS

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.

Photo: Kai T. Dragland/NTNU

Centre Director

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 commersialisation 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

Photo: Trond Johnsen/SINTEF

Chairman of the Board

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 Tvete 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!

Sverre Rye Torben
Director Research & Innovation
Kongsberg Maritime / Integrated Solutions

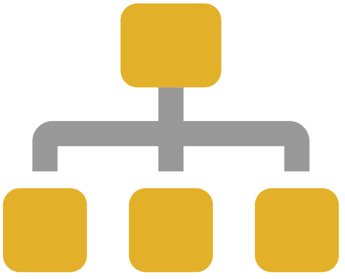
Illustration: Bjarne Stenberg/NTNU

SFI Autoship Facts 2022

8

WORK PACKAGES

25 PARTNERS



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).

Board seminar in June 2022. Photo: Mary Ann Lundteigen/NTNU

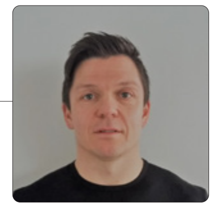
Scientific Advisory Committee Leader
Thor I. Fossen, NTNU

SFI Autoship Centre Board Chairman
Sverre Rye Torben, Kongsberg Maritime

Innovation and Commercialisation Advisory Committee Leader
Kjetil Skaugset, Equinor

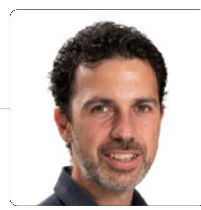
Anastasios Lekkas
Centre Director

Ingeborg Guldal
Administrative Coordinator

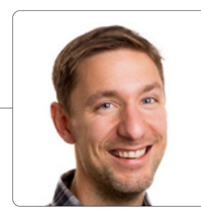


Steve Løkkeberg Harila
Financial Adviser

Edmund Førland Brekke, NTNU
WP 1 - Autoremote



Pierluigi Salvo Rossi, NTNU
WP 2 - Digital Infrastructure



Ole Andreas Alsos, NTNU
WP 3 - Human Factors

Ingrid B. Utne, NTNU
WP 4 - Safety and Assurance

Odd Erik Mørkrid, SINTEF
WP 5 - Sustainable Operations

Trond Johnsen, SINTEF
WP 6 - Use Cases

Kjell Olav Skjølsvik, NTNU
WP 7 - Innovation and Commercialisation

CENTRE MANAGEMENT		
Name	**Dept. of Engineering Cybernetics, NTNU**	**Centre director**
Anastasios Lekkas	Dept. of Engineering Cybernetics, NTNU	Centre Director
Ingrid Bouwer Utne	Dept. of Marine Technology, NTNU	Co-director
Trond Johnsen	SINTEF Ocean	Co-director
Kjell Olav Skjølsvik	Dept. of Marine Technology, NTNU	Innovation Manager
Ingeborg Guldal	Dept. of Engineering Cybernetics, NTNU	Administrative Coordinator

CENTRE BOARD		
Name	**Institution**	**Function**
Sverre Rye Torben	Kongsberg Maritime	Chairman of the Board
Kjell Røang	Forskningsrådet	Observer
Ingelin Steinsland/ Ingrid Schjølberg	NTNU	Board member
Trond Solvang	UiO	Board Member
Sture Holmstrøm	SINTEF AS	Board Member
Arne Fredheim	SINTEF Ocean	Board Member
Bjørn Axel Gran	IFE	Board Member
Hans Anton Tvete	DNV	Board Member
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Ingvild Høgenes Nilsen	Gard	Board Member
John Gabriel Östling	Grieg Star	Board Member
Andreas Simskar Wulvik/ Torbjørn Pedersen	Idletechs	Board member
Sverre Rye Torben	Kongsberg Maritime	Board Member
Hugo Rosano	MacGregor	Board Member
Stephanie Kemna	Maritime Robotics	Board Member
Tom Eystø	Massterly	Board Member
Kenneth Johanson	NCL	Board Member
Bjørg Mathisen Døving	Reach Subsea	Board Member
Henning Huuse	Telia	Board Member

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Trond Langemyr	Kystverket	Board Member
Håvard Gåseidnes	Sjøfartsdirektoratet	Board Member
Terje Meisler	Trondheim havn	Board Member
Kjell-Inge Stellander	Trondheim kommune	Board Member

INNOVATION AND COMMERCIALISATION ADVISORY COMMITTEE		
Representing partner	**Institution**	**Function**
Kjetil Skaugset	Equinor	Leader (2021-2022)
Are Jørgensen	DNV	Permanent member
Oda Ellingsen	Kongsberg Maritime	Permanent member
Vegard Evjen Hovstein	Maritime Robotics	Permanent member
Trond Johnsen	SINTEF Ocean	Permanent member
Kjell Olav Skjølsvik	NTNU	Permanent member
Bjørn Martin Worsøe	Telia	Member (2021-2022)
Joachim Ofstad Næss	Torghatten	Member (2021-2022)

SCIENTIFIC ADVISORY COMMITTEE		
Name	**Institution**	**Function**
Thor I. Fossen	Dept. of Engineering Cybernetics, NTNU	Leader
Paolo Braca	Centre for Maritime Research and Experimentation (CMRE), NATO Science and Technology Organization	Member (2022-2025)
Nikolaos P. Ventikos	School of Naval Architecture and Marine Engineering, National Technical University of Athens (NTUA)	Member (2022-2025)

Illustration: Bjarne Stenberg/NTNU

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.

1 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.

An illustrative image of the type of output the 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.

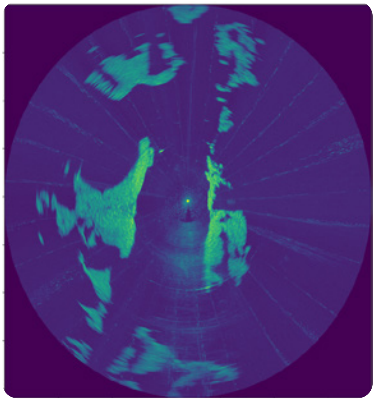
Henrik Dobbe Flemmen

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.



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.

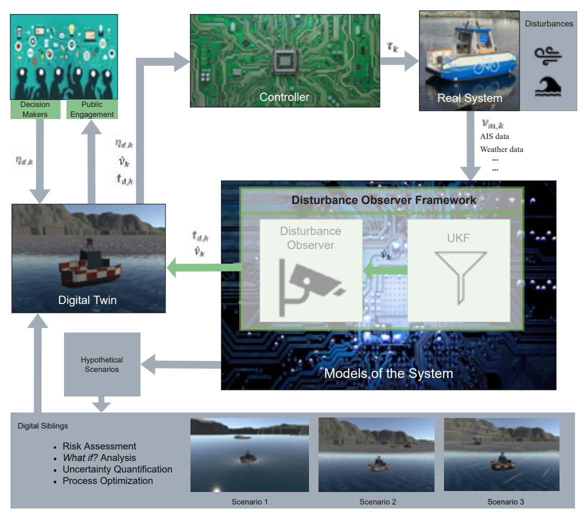
Expected results and innovations
Expected results are novel approaches and algorithms for improving:

- 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.



Concept of a digital twin interacting with a disturbance observer framework.

Simon J.N. Lexau

Docking For Autonomous Ships

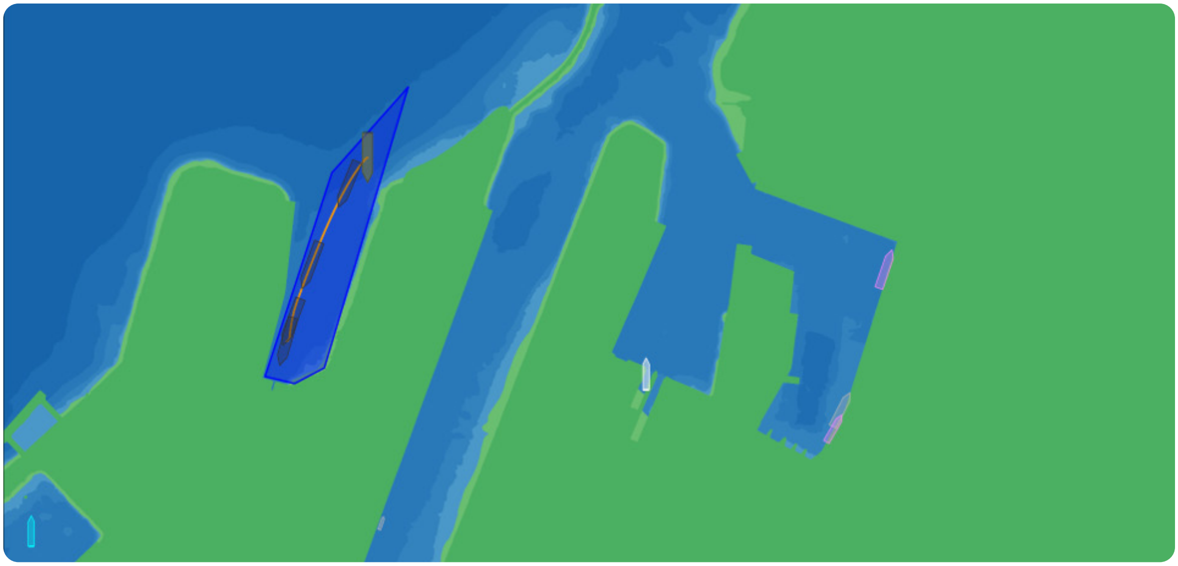
Background including motivation for the research
Unmanned Surface Vessels (USVs) have the potential to revolutionize the shipping industry by reducing the cost and risk associated with human error, and improving the overall efficiency of the industry. My research focuses on developing a system for autonomous 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

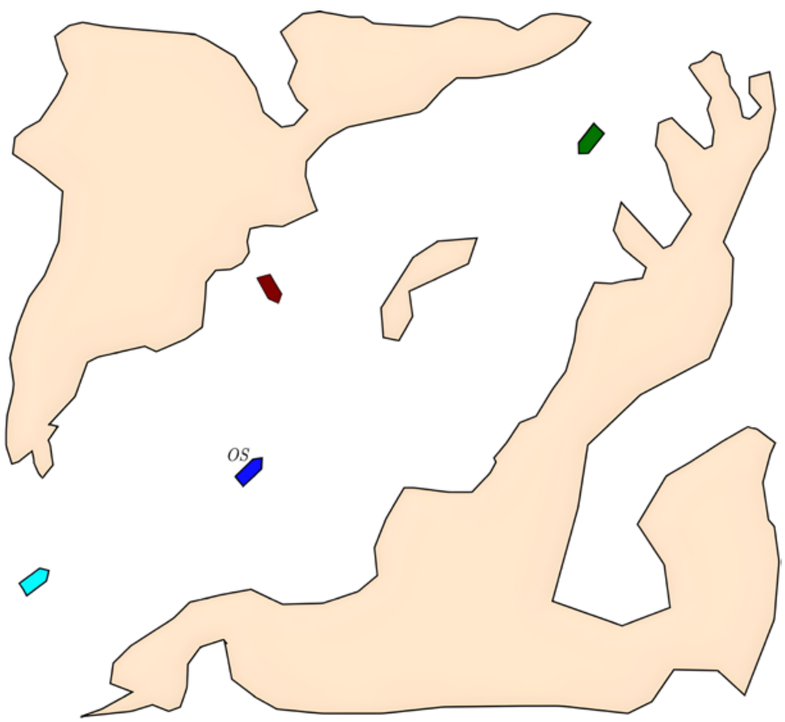
Background including motivation for the research
The image below shows a situation in inland-waters with the own-ship (OS) in blue, where the OS should adhere to the traffic rules, avoid ship collision and avoid grounding. This is a challenging problem, as the geography and nearby vessel configuration 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.

2 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.

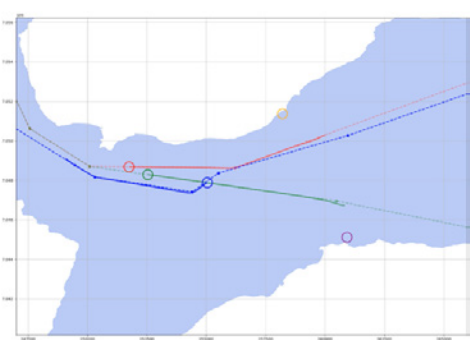
Building on this, we are working on developing a mid-level planner that would collaborate with other ships in advance and calculate collision-free route plans to be exchanged between ships to convey intentions.

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 predefines 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

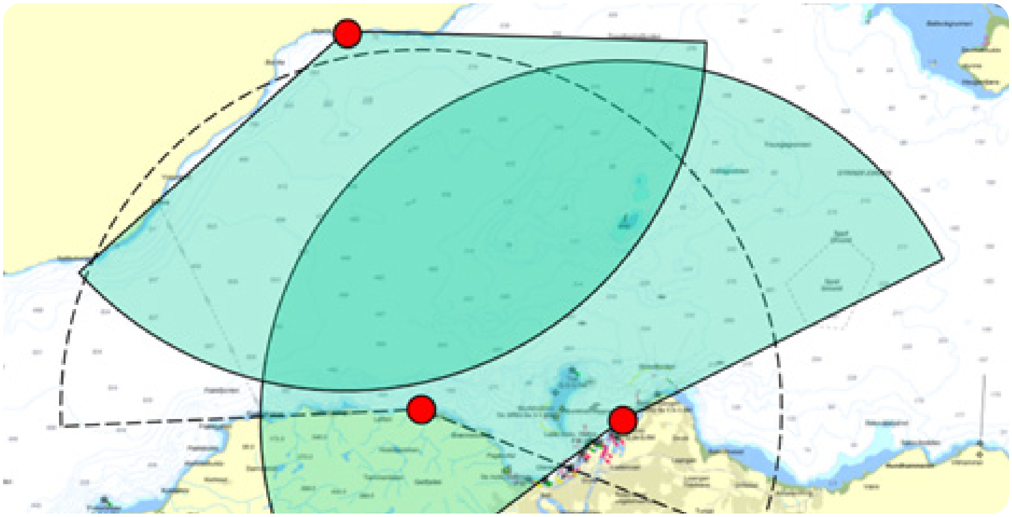
Ship-Shore Radar Network

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.

3 Remote Operation Centres (ROC) and Human factors

WP Leader: Associate Professor Ole Andreas Alsos
NTNU, Department of Design

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.

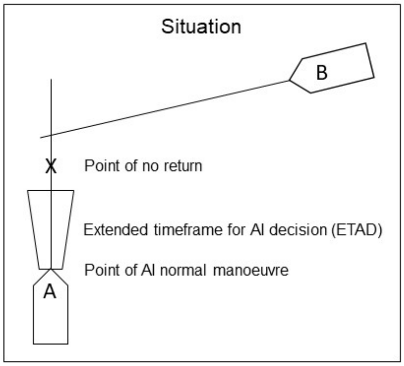


Figure 1: Illustrating a point of no return (X) where vessel A must make a decision to uphold her CPA/TCPA limits and an extended timeframe for AI decision (ETAD). The decision to apply ETAD must be based on either a statistical significance, or a human decision.

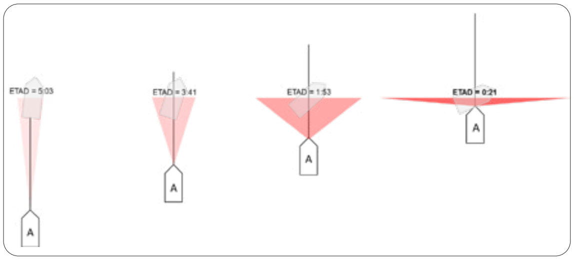


Figure 2: Design sketch for visualization of ETAD, illustrating that an adjustment of course or speed needs to be larger, the longer one awaits a maneuver.

Felix-Marcel Petermann

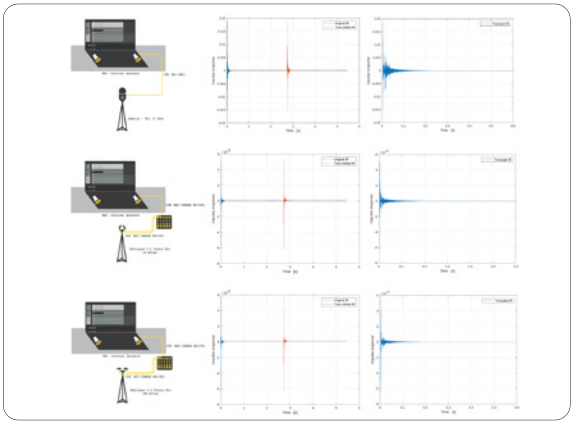
Interaction Design for Autonomous Ships

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.



Setup and results of measurement of impulse response in a room, as a basis for spatialization of sounds in remote control centers.

Visit of Norwegians Minister of Foreign Affairs (NRK TV).

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.

HiNAS 2.0 decision support system, developed by Navikus company and approved by American Bureau of Shipping, https://www.linkedin.com/feed/update/urn:li:activity:7020881900143595520/

Taufik Akbar Sitompul, postdoc

Human-machine interface for remote crane operation

Background including motivation for the research
Cranes 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.

The image shows a map solution running in a 3D graphics engine. The map is based on elevation data, aerial photography, and a point cloud combined from multiple aerial photos. The solution is used to create a more realistic visualization of the area around an autonomous ship.

4 Safety and Assurance

WP Leader: Prof. Ingrid Bouwer Utne,
Dept. Of Marine Technology, NTNU

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.

Photo: Photo: Trond Johnsen/SINTEF

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.

Picture from field trials in Trondheimsfjorden with USV Grethe. The AutoNaut USV has been used for case studies in the PhD research. Photo: Susanna Dybwad Kristensen/NTNU.

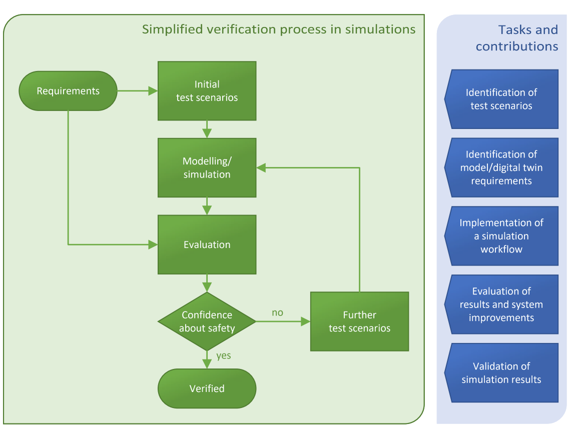
Raffael Wallner

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.



A simplified verification process using simulated safety demonstration and necessary tasks 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.

From the machine room of a ferry. Photo: Trond Johnsen/SINTEF

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.

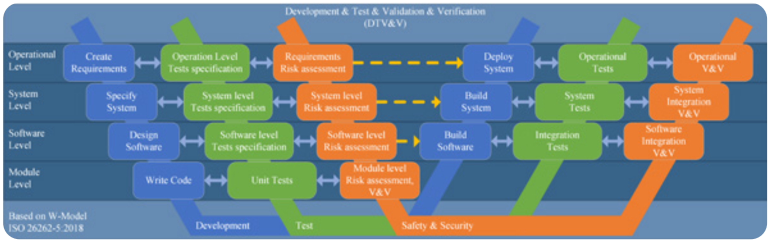
Objective and main tasks
Study the possible impact of software failures on complex transportation systems' safety and security. Elimination of probable software failures leads to increase operational safety and security.

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.

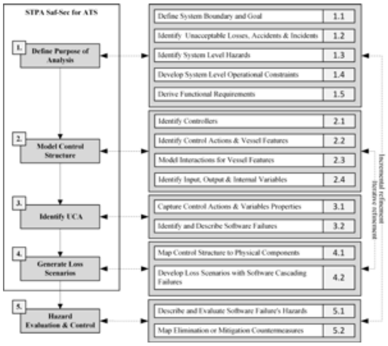
Research approach/ methodology
Software failure classification was done through extensive scientific literature and industrial norms and regulations. In addition, the phenomena of dynamic and static features of software failure were studied on existing autonomous transportation systems in the maritime 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.



Software Safe and secure Design, development, validation and verification process.



STPA SW-SAF-SEC for software failure identification and prevention in system design.

5 Sustainable Operations

WP Leader: Senior project manager, Odd Erik Mørkrid

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.

6 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.

Photo: Piotr Lewandowski/G2Ocean

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.

Photo: North Sea Container Line/NCL

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.

Photo: Torghatten/NTNU

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 main- tenance 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 communica- tion 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.

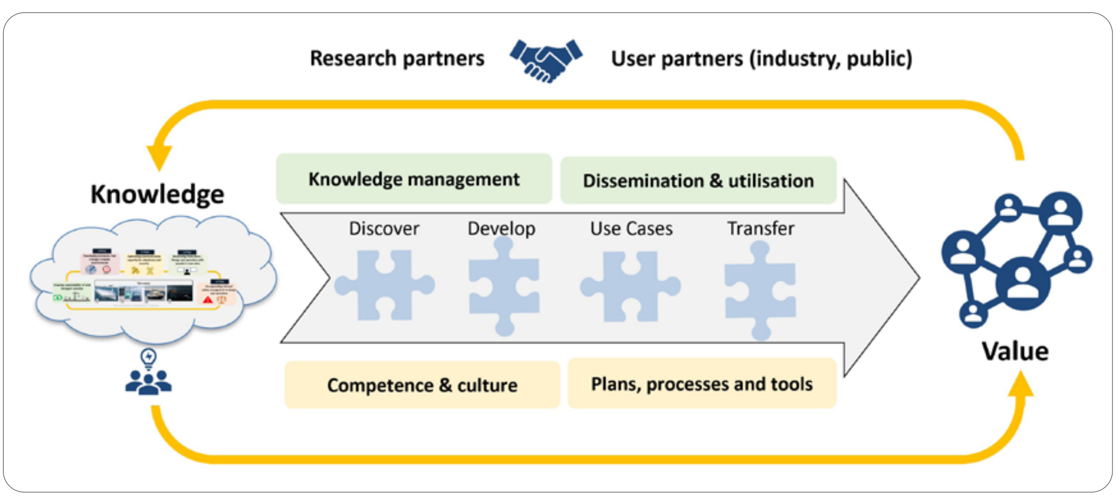
7 Innovation and Commercialisation

WP Leader: Innovation manager Kjell Olav Skjølsvik, Dept. Of Marine Technology, NTNU

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.

Workshop on stage gate models and TRLs as tools. Photo: Kjell Olav Skjølsvik/NTNU



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.

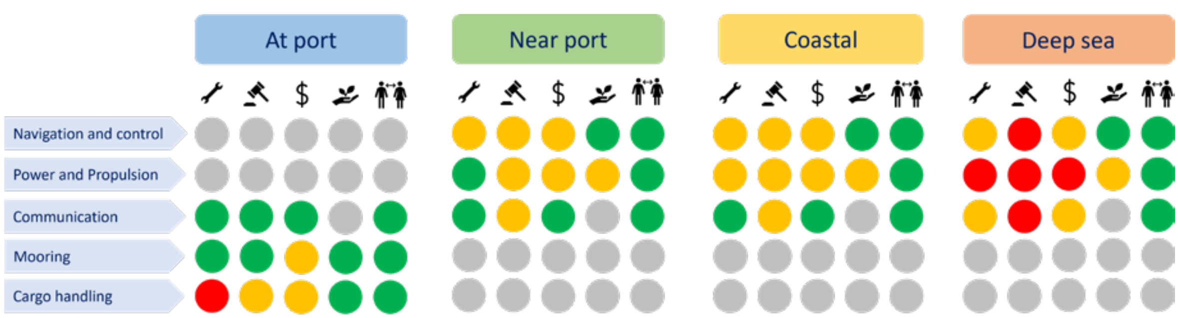


Figure 1: Technical, regulatory, and commercial feasibility

Photos: Kai T. Dragland/NTNU

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.

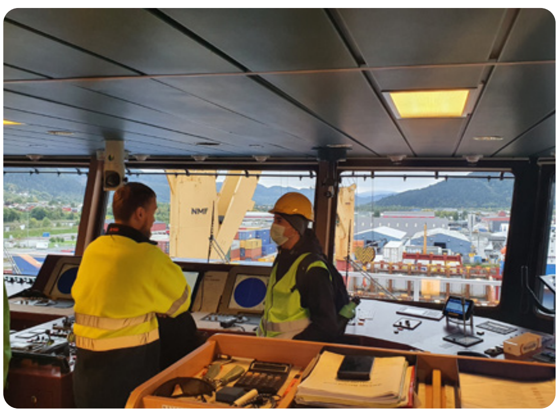
Will passengers still use the ferry without personnel on board? This will be tried out in 2023, when the milliAmpere 2 will move on to an even more ambitious mission.

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:

1. Taufik Akbar Sitompul. 2022. Human–Machine Interface for Remote Crane Operation: A Review. Multimodal Technologies and Interaction 6, 6. https://doi.org/10.3390/mti6060045

2. Taufik Akbar Sitompul. 2022. The Impacts of Different Work Locations and Levels of Automation on Crane Operators' Experiences. In Proceedings of the 34th Australian Conference on Human Computer Interaction (OzCHI '22). ACM, New York, NY, USA. https://doi.org/10.1145/3572921.3572941

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. Rudy Negenborn
Delft university
Prof. Jose Neira
University of Zaragoza
Assoc. Prof. Tim Miller
University of Melbourne

Recruitment

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

Name	PhD project	Work package	Supervisor	Host department
Trym Tengesdal (postdoc)	Risk-based COLAV/ anti-grounding	1	Tor Arne Johansen	Dept. of Engineering Cybernetics, NTNU Gløshaugen
Daniel Menges	SITAW: The ship and its surroundings/collision avoidance	1	Adil Rasheed	Dept. of Engineering Cybernetics, NTNU Gløshaugen
Simon Lexau	Docking and rendevous for USVs	1	Anastasios Lekkas	Dept. of Engineering Cybernetics, NTNU Gløshaugen
Lukas Herrmann	Real-time ship-shore radar	2	Egil Eide	Dept. of Electronic Systems, NTNU Gløshaugen
Luka Grgicevic	Digital Twins for Autonomous Vessels	3	Ottar L. Osen	Dept. of ICT and Natural Sciences, NTNU Ålesund
Taufik Akbar Sitompul (postdoc)	Remote Control for Crane	3	Ole Andreas Alsos	Dept. of Design, NTNU Nyhavna

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)

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

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

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

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

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

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

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

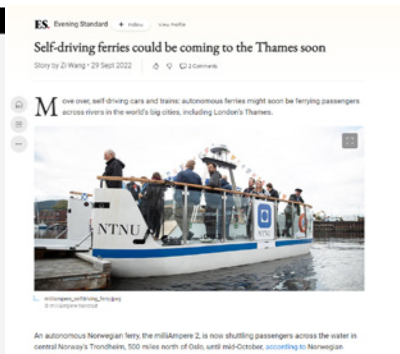
Taufik Akbar Sitompul
Remote Control for Crane
Supervisor: Ole Andreas Alsos (Dept. of Design, NTNU)

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, Adressa, 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.


Egil Eide, Ole Andreas Alsos og Morten Breivik ved NTNU bruker kanalen i Trondheim som forskningslaboratorium. (Foto: Bjørn Lønnum Andreassen)

Norsk selvkjørende ferje skal frakte folk omtrent som i en heis

Norske forskere har laget verdens første prototype av en selvkjørende ferje som kan frakte folk i byområder. Interessen brer seg langt utenfor Norge.


Ole Andreas Alsos forsker på hvordan kontrollrom kan utvikles så en operatør kan følge med flere autonome ferjer som frakter mennesker. (Foto: Bjørn Lønnum Andreassen)

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

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.


4 NYHETER Lørdag 9. april 2022 HAUGESUNDS AVIS

HAUGESUNDS AVIS Lørdag 9. april 2022

Reach Subsea endrer subsea-markedet. Blir beskrevet som en teknologisk revolusjon

Selskapet satser på fjernstyrte skip

Reach Subsea i Haugesund er i gang med en teknologisk revolusjon som kan skremme vannet av kystens offshore-rederier. Selskapet skal etablere en flåte av fjernstyrte ubemannede skip til undervanns-operasjoner.

TERJE STØRKSEN

MARITIM NÆRING: I løpet av neste høst vil to 24 meter lange fjernstyrte skip være å se i Haugesund. Flere vil komme i årene framover.

Reach Subsea har ambisiøse planer for fjernstyrte, mannskapsløse skip. Målet er å etablere en flåte på et titalls fjernstyrte fartøy. Skip som skal erstatte dagens offshorefartøy med et mannskap på mellom 30 og 50 personer.

– Hvorfor ha et overflatefartøy med 30 mann og seks ROV-piloter som venter på at skipet skal komme fram til arbeidsstedet? Hva med fjernstyrte, ubemannede farkoster som frakter ROVene til målet?

Spørsmålet har i flere år vært tema hos Reach Subsea, daglig leder Jostein Alendal og prosjektleder Bjørg Mathisen Døving.

Hvorfor ha et overflatefartøy med 30 mann og seks ROV-piloter som venter på at skipet skal komme fram til arbeidsstedet?
LEDELSEN I REACH SUBSEA

NY TIDSALDER: Reach Subseas administrerende direktør Jostein Alendal og prosjektleder Bjørg Mathisen Døving tar selskapet inn i en ny tidsalder. FOTO: TERJE STØRKSEN

SKIPENE: Kongsberg Maritime har tegnet og designet de fjernstyrte 24 meter lange skipene for Reach Subsea. ILLUSTRASJON: REACH SUBSEA

ROVENE SENKES: ROVene blir senket fra skipets bunn og vil bli styrt fra kontrollrommet i Haugesund. ILLUSTRASJON: REACH SUBSEA

HAVVIND: De ubemannede fartøyene kan også få en rolle i utbyggingen av havvind. ILLUSTRASJON: REACH SUBSEA

Haugesunds Avis, «Selskapet satser på fjernstyrte skip», 09.04.2022.

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/Fremtidens Industri*

Presenting the SFI to the Norwegian Association for Autonomous Ships. *Mary Ann Lundteigen presenting the SFI at a NFAS seminar in June. Photo: Marius Tvinnerheim/Fremtidens Industri*

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.

Presenting the milliAmpere 2 trial: Felix Peterman, Mina Saghafian and Ole Andreas Alsos (NTNU). Photo: Ingeborg Guldal/NTNU

Coffee break during the SFI Days. Photo: Ingeborg Guldal/NTNU

Pauline Røstum Bellingmo and Odd Erik Mørkrid presenting a Feasibility study for an Unmanned Deep Sea Bulk Ship and Short Sea Container Ship, with Trond Johnsen, (SINTEF). Photo: Ingeborg Guldal/NTNU

Current status of ongoing MASS projects and identified gaps for international scale-up by An-Magritt Ryste (Kongsberg Maritime). Photo: Ingeborg Guldal/NTNU

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.

Parallel session for Work Package 4. Photo: Ingeborg Guldal/NTNU

Parallel session for Work Package 3. Photo: Ingeborg Guldal/NTNU

Parallel session for Work Package 1-2. Photo: Ingeborg Guldal/NTNU

Parallel session for Work Package 5. Photo: Ingeborg Guldal/NTNU

Publications and Presentations in 2022

Type	Name/description	Name of journal/conference/ book	Main author
Journal articles	Collaborative Collision Avoidance for Autonomous Ships Using Informed Scenario-Based Model Predictive Control	IFAC-PapersOnLine	Melih Akdag, Thor I. Fossen and Tor Arne Johansen
	Collaborative collision avoidance for Maritime Autonomous Surface Ships: A review	Ocean Engineering	Melih Akdag, Petter Solnør and Tor Arne Johansen
	Safe and efficient maneuvering of a Maritime Autonomous Surface Ship (MASS) during encounters at sea: A novel approach	Maritime Transport Research	Andreas Madsen, Magne Aarset and Ole Andreas Alsos
	Maritime Autonomous Surface Ships: Automation Transparency for Nearby Vessels	Journal of Physics: Conference Series (JPCS)	Ole Andreas Alsos, Philip Hodne, Oskar Kristoffer Skåden and Thomas Porathe
	NTNU Shore Control Lab: Designing shore control centres in the age of autonomous ships	Journal of Physics: Conference Series (JPCS)	Ole Andreas Alsos, Erik A. Veitch, Leander S. Pantelatos, Kjetil Vasstein, Egil Eide, Felix-Marcel Petermann and Morten Breivik
	milliAmpere: An Autonomous Ferry Prototype	Journal of Physics: Conference Series (JPCS)	Edmund F. Brekke, Egil Eide, Bjørn-Olav H. Eriksen, Erik F. Wilthil, Morten Breivik, Even Skjellaug, Øystein K. Helgesen, Anastasios M. Lekkas, Andreas B. Martinsen, Emil H. Thyri, Tobias V. R. Torben, Erik A. Veitch, Ole Andreas Alsos, Tor Arne Johansen
	Online wave direction and wave number estimation from surface vessel motions using distributed inertial measurement arrays and phase-time-path-differences	Ocean Engineering	Johann Alexander Dirdal, Roger Skjetne, Jan Roháč, Thor I. Fossen
	Heterogeneous multi-sensor tracking for an autonomous surface vehicle in a littoral environment	Ocean Engineering	Øystein Karstad Helgesen, Kjetil Vasstein, Edmund Førland Brekke, Annette Stahl
	A Rudimentary Mission Planning System for Marine Autonomous Surface Ships	IFAC-PapersOnLine	Miguel Hinostroza and Anastasios M. Lekkas
	Reinforcement learning-based NMPC for tracking control of ASVs: Theory and experiments	Control Engineering Practice	Andreas Bell Martinsen, Anastasios M. Lekkas and Sebastien Gros

	Programming "The ordinary practice of seamen" into the AI-navigator: friendly and communicative interaction design between autonomous and manned vessels	Necesse	Thomas Porathe
	Human–Machine Interface for Remote Crane Operation: A Review	Multimodal Technologies and Interaction	Taufik Akbar Sitompul
	Ship Collision Avoidance and Anti Grounding Using Parallelized Cost Evaluation in Probabilistic Scenario-Based Model Predictive Control	IEEE Access	Trym Tengesdal, Tor Arne Johansen, Tom Daniel Grande and Simon André Johnsen Blindheim
	A Guidance and Maneuvering Control System Design With Anti-Collision Using Stream Functions With Vortex Flows for Autonomous Marine Vessels	IEEE Transactions on Control Systems Technology	Hongyu Zhou, Zhengru Ren, Mathias Marley and Roger Skjetne
	Static obstacle avoidance and docking of ASVs using computational geometry and numerical optimal control	IFAC-PapersOnLine	Petter K. Ødven, Andreas Bell Martinsen and Anastasios M. Lekkas
Conference papers/ Workshop presentations	Collaborative Collision Avoidance for Autonomous Ships Using Informed Scenario-Based Model Predictive Control	14th IFAC Conference on Control Applications in Marine Systems	Melih Akdag, Thor I. Fossen and Tor Arne Johansen
	milliAmpere2 and NTNU Shore Control Lab	International Seminar with TalTech, Estonia	Ole Andreas Alsos
	Presentation of MIDAS, NTNU Shore Control Lab, and milliAmpere2	MIT Media Lab, USA	Ole Andreas Alsos
	Presentation of MIDAS, NTNU Shore Control Lab, and milliAmpere2	Universidad Federal do Rio De Janeiro, Brasil	Ole Andreas Alsos
	Hypothesis Exploration in Multiple Hypothesis Tracking with Multiple Clusters	25th International Conference on Information Fusion - FUSION	Edmund Førland Brekke and Lars-Christian Ness Tokle
	STPA-based hazard analysis of a ship collision avoidance and stability monitoring system	10th European STAMP Workshop and Conference	Spencer A. Dugan, Ingrid B. Utne, Roger Skjetne, Jakub Montewka, Mateusz Gil and Krzysztof Wrobel
	Unsupervised Clustering of Marine Vessel Trajectories in Historical AIS Database	25th International Conference on Information Fusion - FUSION	Ravinder Praveen Kumar Jain, Edmund Førland Brekke and Adil Rasheed
	Prediction and evaluation of an angle of heel due to turning maneuver of small training ships: comparison of dynamic analysis and static design criteria	Proceedings of the 15th International Symposium on Practical Design of Ships and Other Floating Structures (PRADS 2022, University of Zagreb)	Przemyslaw Krata, Tomasz Hinz, Spencer A. Dugan, Mathias H. Marley and Jakub Montewka

	DSA-inspired assessment of autonomous ships stability during turning maneuver	Proceedings of the 18th International Ship Stability Workshop (Gdansk University of Technology)	Przemyslaw Krata, Tomasz Hinz, Mathias H. Marley, Spencer A. Dugan, Mateusz Gil, Jakub Montewka and Roger Skjetne
	Dynamic Risk Analysis of Maritime Autonomous Surface Ships	Probabilistic Safety Assessment and Management PSAM 16	Susanna Dybwad Kristensen, Yiliu Liu and Ingrid Bouwer Utne
	Safety and Assurance of Autonomous Ships: Framing of Research Actions	MTEC/ICMASS 2022	Mary Ann Lundteigen and Ingrid Bouwer Utne
	When do meeting ships of a MASS deviate from COLREG?	Fjordkonferansen 2022	Andreas Solnørdal Madsen
	Mitigating Force Oscillations in a Wave Energy Converter Using Control Barrier Functions	41st International Conference on Ocean, Offshore and Arctic Engineering Volume 8: Ocean Renewable Energy. The American Society of Mechanical Engineers (ASME)	Mathias H. Marley and Roger Skjetne
	Increasing the Usability of Audio Alerts with Voice Instructions on Ship's Bridges	Human Factors in Accessibility and Assistive Technology. AHFE (2022) International Conference	Felix-Marcel Petermann, Malene Liavaag, Julie Karine Schmidt Solberg, Ole Andreas Alsos and Erik Styhr Petersen
	Collision Avoidance for autonomous ships (MASS): making assumptions about other ships intended routes.	Proceedings of the 32nd European Safety and Reliability Conference (ESREL 2022)	Thomas Porathe
	Remote Monitoring of Autonomous Ships: Quickly Getting into the Loop Display (QGILD)	Human Factors in Transportation. USA: Applied Human Factors and Ergonomics International (AHFE International)	Thomas Porathe
	Where does the pilot go when the autonomous ship has no bridge? MASS Routing Service and smart Local Information Centres	Proceedings of the Autonomous Ship Conference 2022	Thomas Porathe
	The Impacts of Different Work Locations and Levels of Automation on Crane Operators' Experiences: A Study in a Container Terminal in Indonesia	OzCHI '22: Proceedings of the 34th Australian Conference on Human-Computer Interaction. Association for Computing Machinery (ACM)	Taufik Akbar Sitompul
	Keynote: Robotics and vision-based autonomic systems in challenging environments	2022 EIROforum Topical Workshop on Robotics & Remote Operation	Annette Stahl
	Seeing the Unseen: Visual Perception for Autonomous Robots	AMOS Days	Annette Stahl

	Collision Avoidance Rules and their application to Autonomous Vessels	Presentation at the Arctic University of Norway (UiT)	Ayoub Tailoussane
	Collision Avoidance Rules and their application to Autonomous Vessels: The role of legal dogmatics in the development of COLREGS-compliant Autonomous Vessels	Nordisk Sjørettsseminar 2022	Ayoub Tailoussane
	Compliance with the ColRegs and predictable navigation – Some legal challenges	SFI AutoShip webinar on regulatory challenges and possibilities for unmanned ships	Ayoub Tailoussane
	Joint Stochastic Prediction of Vessel Kinematics and Destination based on a Maritime Traffic Graph	IEEE 2022 3rd International Conference on Electrical, Computer, Communications and Mechatronics Engineering (ICECCME)	Trym Tengesdal, Leonardo M. Millefiori, Paolo Braca and Edmund Førland Brekke
	Approaches to Utilize Digital Twins in Safety Demonstration and Verification of Automated and Autonomously Controlled Systems.	Proceedings of the 32nd European Safety and Reliability Conference (ESREL 2022).	Raffael Andrea Wallner and Mary Ann Lundteigen
Reports	SINTEF report	Automatic Mooring: Technical Gap Analysis	Pauline Røstum Bellingmo and Ulrik Jørgensen
Other presentations and selected events	Autonome skip og automasjonstransparens	Avanserte Fartøyer 2022	Ole Andreas Alsos
	Invited keynote: Man in future maritime operations	Ship Technology Days	Ole Andreas Alsos
	Invited talk: When the captain goes ashore	Ocean Autonomy Conference	Ole Andreas Alsos
	Keynote: How to design for trust	Industrial Design Conference 2022	Ole Andreas Alsos
	Keynote: Human factors in the age of autonomous systems	Nordic Ergonomics and Human Factors Society Conference 2022 (NES)	Ole Andreas Alsos
	milliAmpere2 trial og fjernoperasjon	Sjøfartsdirektoratet Ny-teknologi samling	Ole Andreas Alsos
	Mulighetene som autonome operasjoner gir til videreutvikling av kystnært havbruk	Brohodekonferansen 2022	Ole Andreas Alsos
	Presentasjon av milliAmpere2 og Shore Control Lab	Forskningstorget	Ole Andreas Alsos

	Presentation and demonstration of milliAmpere2	Opening milliAmpere2	Ole Andreas Alsos
	Presentation of milliAmpere2 and Shore Control Lab	NTNU Researchers' Night	Ole Andreas Alsos
	Presentation of SFI Autoship and the milliAmpere2 trial	SMASH, Nederlands Forum Smart Shipping	Ole Andreas Alsos
	Presentation of the Shore Control Lab, milliAmpere2	Media visit by Leon Kirchen, Süddetuche Zeitung	Ole Andreas Alsos
	Prøvedrift av verdens første autonome byferge	Norsk forum for autonome skip (NFAS) Årsmøte	Ole Andreas Alsos
	Presentation of NTNU Shore Control Lab	Visit from Minister of Trade and Industry and Trondheim Major	Ole Andreas Alsos
	Exhibition of NTNU Shore Control Lab and MilliAmpere 2	Ocean Week 2022 - An Ocean of Knowledge	Ole Andreas Alsos and Felix-Marcel Petermann
	Presentation of Shore Control Lab	Visit from Norwegian Minister of Fisheries and Ocean Politics	Ole Andreas Alsos and Felix-Marcel Petermann
	Norsk selvkjørende ferje skal frakte folk omtrent som i en heis.	Forskning.no	Bjørn Lønnum Andreassen, Ole Andreas Alsos, Morten Breivik and Egil Eide
	SFI AutoShip - An Introduction	Norwegian Maritime Authority Workshop	Anastasios M. Lekkas
	SFI AutoShip - An Introduction	SMASH! visit to Norway	Anastasios M. Lekkas
	Maritime Data Space: Trygg og effektiv informasjonsutveksling.	Haugesundkonferansen 2022	Dag Atle Nesheim
	From humans to machines – Autonomous Vessels and the application of the COLREGs.	Presentation at the Norwegian Maritime Authority	Ayoub Tailoussane

Master Students 2022

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

Annual Accounts for 2022

All figures in 1000 NOK.

FUNDING	AMOUNT
The Research Council	12 325
The Host Institution (NTNU)	9 896
Research Partners*	1 476
Enterprise partners**	8 386
Public partners***	29
Total	**32 112**

COSTS	AMOUNT
The Host Institution (NTNU)	19 031
Research Partners*	8 756
Enterprise partners**	4 296
Public partners***	29
Total	**32 112**

*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

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	NTNU	MAIN RESEARCH AREA
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	Robotic vision
Edmund Brekke	Dept. of Engineering Cybernetics	Sensor fusion
Egil Eide	Dept. of Electronic Systems	Sensors and autonomous systems
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	Signal processing, communication theory, data fusion and machine learning
Robin Bye	Dept. of ICT and Natural Sciences	Explainable 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)	MAIN RESEARCH AREA
Trond Solvang	UiO, Scandinavian Institute of Maritime Law	Maritime law, torts law, contract law

KEY RESEARCHERS	SINTEF	MAIN RESEARCH AREA
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	Sensor fusion, estimation
Marialena Vagia	SINTEF Digital	Cargo handling, control systems
Mariann Merz	SINTEF Digital	Autonomy, risk assessment, path planning, control algorithms
Odd Erik Mørkrid	SINTEF Ocean	Maritime logistics and autonomous shipping
Pauline Røstum Bellingmo	SINTEF Ocean	Maritime digitalization, autonomous shipping
Trond Johnsen	SINTEF Ocean	Maritime transport and logistics
Ulrik Jørgensen	SINTEF Ocean	Autonomous maritime systems and simulations
Ørnulf Jan Rødseth	SINTEF Ocean	Maritime digitalization, autonomous control system design

KEY RESEARCHERS	IFE	MAIN RESEARCH AREA
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

NAME	SEX	NATIONALITY	PERIOD	TOPIC
Alojz Gomola	M	Slovakian	12.07.2021-11.07.2023	Dynamic and simulation-based risk modeling for operational decision support and verification
Trym Tengesdal	M	Norwegian	13.09.2022-12.09.2024	Risk-based COLAV/anti-grounding
Taufik Akbar Sitompul	M	Indonesian	01.02.2022-01.02.2024	Remote Control for Crane/ Design of human-machine interface

POSTDOCTORAL RESEARCHERS WORKING ON PROJECTS IN THE CENTRE WITH FINANCIAL SUPPORT FROM OTHER SOURCES

NAME	SEX	NATIONALITY	PERIOD	TOPIC	FUNDING
Praveen Jain	M	Indian	01.05.2022-01.09.2023	Long-term vessel prediction	Autosit/ MAROFF/NFR
Mina Saghafian	F	Dutch	01.08.2022-01.07.2025	Human Factors, Safety and Design in Safety Critical Systems, Automation and Remote Operation Technologies	NTNU/SINTEF

PHD STUDENTS WITH FINANCIAL SUPPORT FROM THE CENTRE BUDGET

NAME	SEX	NATIONALITY	PERIOD	TOPIC
Melih Akdag	M	Turkish	20.05.2021- 19.05.2024	Collaborative collision avoidance for autonomous ships
Susanna Dybwad Kristensen	F	Norwegian	16.08.2021- 15.07.2024	Online risk modeling of autonomous ships
Henrik Dobbe Flemmen	M	Norwegian	01.10.2021-30.09.2024	Non-GNSS localization for USVs (aka SLAM)
Emil Martens	M	Norwegian	11.08.2021- 11.08.2026	Multi-sensor objetc detection and classification
Felix Peterman	M	German	01.08.2021- 31.07.2025	Interaction Design
Andreas Nygard Madsen	M	Norwegian	01.09.2021- 31.07.2024	AI decision transparency in autonomous maritime operations
Eirik Fagerhaug	M	Norwegian	16.08.2021-15.08.2024	Explainable AI for autonomous ships
Spencer Dugan	M	American	01.09.2021-31.08.2024	Risk acceptance and operational constraints in risk modeling of autonomous operations.
Ayoub Tailoussane	M	Moroccan	01.09.2021-31.08.2024	COLREGS and their connection with autonomous vessels
Raffael Wallner	M	Austrian	28.11.2021-27.11.2024	Safety demonstration of autonomous control systems using digital twin
Simon Lexau	M	Norwegian	23.08.2022-22.08.2025	Docking and rendevous for USVs
Lukas Herrmann	M	German	01.06.2022-31.05.2025	Real-time ship-shore radar
Daniel Menges	M	German	17.01.2022-16.01.2025	SITAW: The ship and its surroundings/collision avoidance
Luka Grgicevic	M	Croatian	31.01.2022-30.01.2025	Decision Support Systems for Autonomous Vessels

PHD STUDENTS WORKING ON PROJECTS IN THE CENTRE WITH FINANCIAL SUPPORT FROM OTHER SOURCES				
NAME	**SEX**	**NATIONALITY**	**PERIOD**	**TOPIC**
Audun Hem	M	Norwegian	01.10.2020-30.11.2023	PhD in the Autosit project: Autonomous ships, intentions and situational awareness
Øystein Helgesen	M	Norwegian	01.08.2022-31.07.2023	Sensor Fusion and Situational Awareness for autonomous urban ferries in the Autoferry project. Research topics include perception, sensor fusion and target tracking.
Lars-Christian Tokle	M	Norwegian	01.01.2019-01.03.2024	Sensor Fusion and Situational Awareness for autonomous urban ferries in the Autoferry project. Research topics include sensor fusion for SLAM and target tracking.
Inger Berge Hagen	F	Norwegian	01.01.2020-31.12.2022	Maritime Collision Avoidance
Johan Bakken Sørensen	M	Norwegian	01.08.2022-31.07.2025	Safety and assurance of autonomous ships
Erik Veitch	M	Finnish	01.10.2020-01.07.2023	Human-AI interaction in highly automated ships. How can we safely operate autonomous ships?

SFI·AUTOSHIP

Autonomous ships