ANNUAL REPORT 2023

SFI• AUTOSHIP

Autonomous ships for safe and sustainable operations

Norwegian Centre for Research-based Innovation

SFI• AUTOSHIP

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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

Anastasios Lekkas
Centre Director SFI AutoShip

Centre Director

Following the first two years of SFI AutoShip, where a lot of effort was put on hiring excellent researchers, defining the scope of the use cases, and setting up and promoting the Centre's activities, we have entered a new phase. In 2023 tighter collaboration between our researchers and partners has been the top priority in the Centre.

We held a number of events, with the main ones being the SFI days, two researcher workshops, and a parallel session on autonomous ships as part of Ocean Week. In all cases, our events were marked by high attendance and excellent contributions by our partners, whose engagement in the Centre's research activities is steadily growing. At the moment, several of our researchers collaborate directly with our partners, and ongoing monthly discussions at management level aim at further increasing the numbers. The good collaboration among our partners was also manifested through 7 webinars that were co-organized by more than 10 members of our consortium. One of the webinars resulted in the newly-established working group on COLREGs, which will commence its activities in early 2024. SFI AutoShip researchers got several opportunities to visit our partners' premises and facilities, not only in Norway, but also in the Netherlands and the UK.

During 2023, our research capacity was increased to a total of 18 PhDs, 2 postdocs and one researcher, while 1 postdoc completed his project. Our researchers published very interesting results on a wide range of topics, and our dissemination activities have continued, both nationally and abroad. In total, close to 150 results were registered by the Centre in 2023, including scientific publications, popular science publications, dissemination activities and graduated MSc theses. Even more importantly, following the adoption of our utilization plan by the Board, we put a lot of emphasis on training our researchers in pursuing innovation, starting with an innovation workshop in March, as well as several additional sessions on commercializing results, submitting DOFIs and collaborating with NTNU Technology Transfer. As a result, 17 innovation leads were developed, and researchers pitched their leads to an expert panel representing the SFI AutoShip management and partners, NTNU Technology Transfer and SFU Engage. Three of these innovation leads evolved into submitted DOFIs by our researchers, where commercialization potential has been identified.

We had the pleasure to interact and host our scientific advisory committee during SFI AutoShip days. The committee consists of three international experts that provided invaluable feedback as to where the Centre is standing from an international viewpoint, and suggestions for the future. In addition, our researchers who are affiliated to the PERSEUS project planned visits abroad that are ongoing.

In anticipation of many exciting joint results during 2024, I want to thank all partners for their efforts and eagerness to make SFI AutoShip an excellent environment for state-of-the-art research within autonomous ship technology!

Photo: Trond Johnsen/SINTEF

Øystein Engelhardtsen
Group Leader Ship Autonomy -
Group Research and Development
DNV

Chairman of the Board

As the chairman of the board for the research center SFI AutoShip, I am very pleased to present the 2023 annual report. I would also like to provide a warm welcome to the new researchers and industry partners that has joined us last year.

2023 has been marked by a year for further growth, combined with a focus on increased cooperation between industry partners and academic researchers. As the center is now entering its fourth year of operation, I am very happy to see that SFI AutoShip has grown and matured into a forceful research-center with the capacity to deliver state-of-the art research results across a wide range of scientific fields. Our researchers have already published a significant number of relevant and high-quality scientific papers, making the center a force to be reckoned with on the international arena within research of autonomous ships. An aspect that truly makes the center stand out, is how solid theoretical research is combined with industry expertise and experiments and physical trials.

Providing industry relevant results is key for any successful SFI and this is something that requires continuous attention to achieve. To enable this, our researchers and industrial experts need to work together and share their knowledge and expertise. In 2023 we have further increased the focus on connecting people and knowledge across the center. A series of webinars on selected topics has been arranged, covering many of the key research areas, including presenters from several industry partners. These webinars have been very well attended and has also been praised by many of the participants in the consortium. The webinar on COLREG have resulted in the newly formed working group on COLREG which will establish another arena for cooperation. In addition to this, we have seen increased participation from several industry partners in the researcher workshops, enabling the academic researchers to discuss their problems and solutions directly with industry experts. This year we will encourage the industry partners to present pressing industry-relevant research questions to the researchers and discuss potential collaborations around these. Finally, the SFI days was a big success, very well attended and with excellent presentations from many partners and researchers. Going forward, we will continue our focus connecting people and knowledge between the researchers and the industry partners with the ambition of creating results that are directly relevant for the industry.

As chairman of the board, I would like to express a big thanks to the center director and administrative coordinator for their stamina, dedication, and creativity that has played a major role in the success of the SFI up until now. I would also like to thank all our partners for their efforts and eagerness to make SFI AutoShip an excellent environment for state-of-the-art research and innovation within autonomous ship technology. I am grateful for the support and collaboration from all our partners, and I look forward to achieving many exciting joint results in the coming years.

Illustration: Bjarne Stenberg/NTNU

SFI Autoship Facts 2023

8

WORK PACKAGES

24 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 meeting in June 2023 hosted by Telia. Henning Huuse showing the Board around in the 5G Lab. Photo: Ingeborg Guldal/NTNU

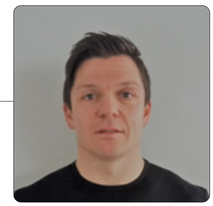
Scientific Advisory Committee Leader
Thor I. Fossen, NTNU

SFI Autoship Centre Board Chairman
Øystein Engelhardtsen, DNV

Innovation and Commercialisation Advisory Committee Leader
Kjetil Skaugset, Equinor

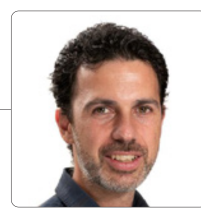
Anastasios Lekkas
Centre Director

Ingeborg Guldal
Administrative Coordinator

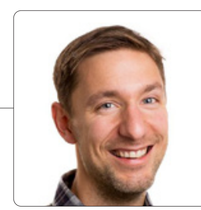


Steve Løkkeberg Harila
Financial Adviser

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**
Øystein Engelhardtsen	DNV	Chairman of the Board
Kjell Røang	Forskningsrådet	Board Member
Kjell Magne Leirgulen	Embron	Board Member
Kjetil Skaugset	Equinor	Board Member
Jan Cees Sabel	Fugro	Board Member
Ingvild Høgenes Nilsen	Gard	Board Member
John Gabriel Östling	Grieg Star	Board Member
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Sverre Rye Torben	Kongsberg Maritime	Board Member
Trond Langemyr	Kystverket	Board Member
Hugo Rosano	MacGregor	Board Member
Vegard Evjen Hovstein	Maritime Robotics	Board Member
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Sture Holmstrøm	SINTEF AS	Board Member
Arne Fredheim	SINTEF Ocean	Board Member
Håvard Gåseidnes	Sjøfartsdirektoratet	Board Member
Henning Huuse	Telia	Board Member
Jan-Egil Wagnild	Torghatten	Board Member
Terje Meisler	Trondheim Havn	Board Member
Øyvind Tanum	Trondheim kommune	Board Member
Trond Solvang	UiO	Board Member

INNOVATION AND COMMERCIALISATION ADVISORY COMMITTEE		
Representing partner	**Institution**	**Function**
Kjetil Skaugset	Equinor	Leader
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 (2021-2023)
Joachim Ofstad Næss	Torghatten	Member (2021-2023)

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. The 7 first Work Packages are presented on the following pages and shows the ongoing research activities in the Centre. Some highlights from the final Work Package can be found in the subchapter on Media and Events.

1

AutoRemote

WP Leader: 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 detection, tracking, localization, docking and collision avoidance in coastal waters. In 2023, researchers in the work package published papers on topics such as digital twins, disturbance observers, multi-target tracking using various approaches, radar-based localization, automated docking, collision avoidance and predictive safety filters. Several master students were connected to the work package, and worked on related topics, as well as path planning, intention modeling, data acquisition and machine learning. Much of this research was focused on simulation studies and implementation of algorithms using data recorded by the consortium partners. Both are important to pave the way for real-world closed loop experiments, where sensor fusion algorithms are used as input to control systems and/or decision support.

Photo: Sander Furre

Emil Martens

Sensor rig for data acquisition in maritime environments

Problem statement

Development of new methods within the domain of autonomous surface vessels (ASVs) depends on high quality datasets. Research vessels such as MilliAmpere 2 can be used for data collection, but this generally requires the involvement of multiple people and a significant amount of time. Testing new types of sensors can also be challenging as they must be integrated with the existing vessel.

Proposed solution

A stand-alone sensor platform has been developed to enable easy and efficient data acquisition. The platform is lightweight and designed to be carried and operated by a single human or be temporarily attached to any vessel. The rig is equipped with a Jetson Orin AGX with four separate PoE ports for easy integration with different sensors. Two GNSS receivers and an IMU provides accurate pose information and time synchronization for connected devices. Currently two Polarization cameras are mounted to collect stereo polarization video which will be used in research on water surface segmentation.

Main activities during 2023

- Developed a human portable sensor platform for easy data acquisition in maritime environments.
- Enabled synchronization of sensors to GNSS time using a PPS-enabled Linux kernel and PTP.
- Wrote an efficient parsing pipeline for polarization video in CUDA.
- Designed tracking boxes to generate accurate 6DOF ground truth pose data.
- Innovation pitch, SFI Days 2023.

Operation of the sensor rig. Visualisation of the benefit of using polarization cameras. The colour intensity shows the degree of polarization, and the hue shows the angle of polarization.

Henrik Dobbe Flemmen

Radar based SLAM for autonomous ships

Problem statement

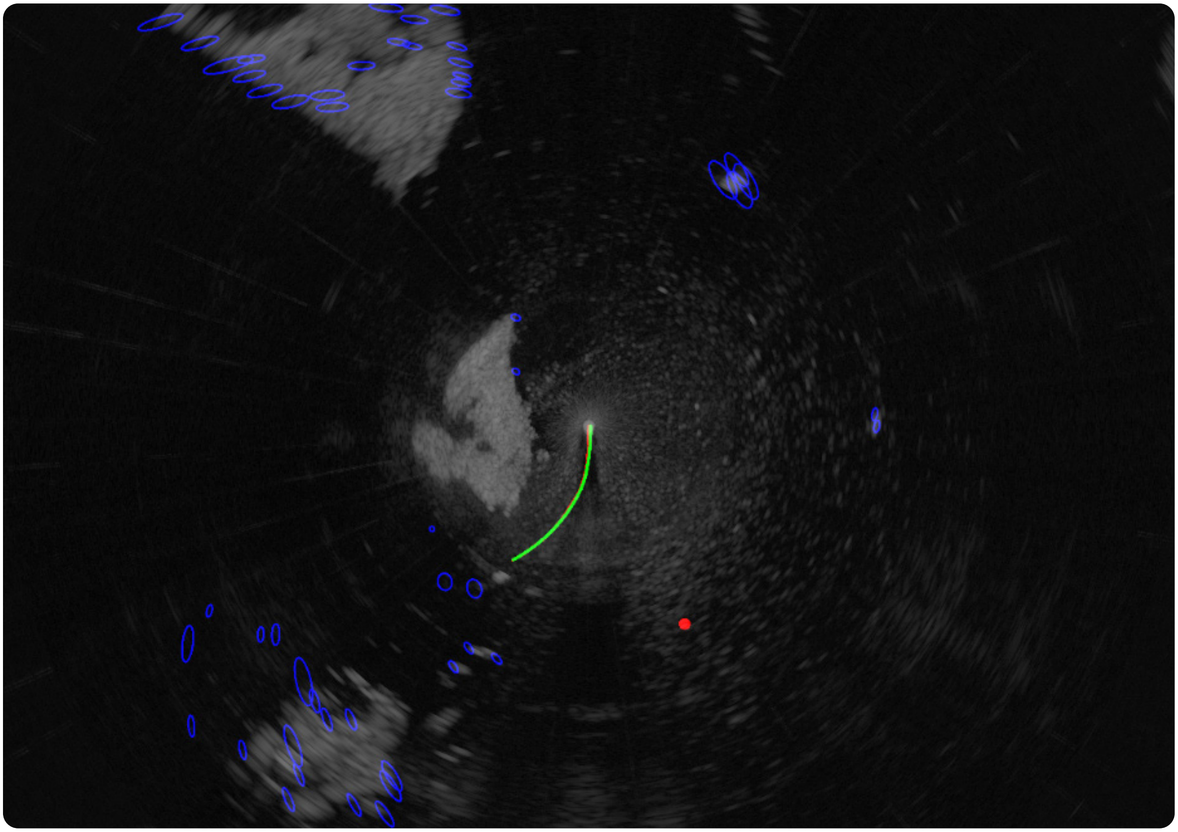
Global Navigation Satellite Systems (GNSS) is the primary technology for positioning for both manned and unmanned ships. That is great, because GNSS is highly available, very precise and has high integrity. Still, it might fail in rare cases. Traditional ships can in those cases fall back to traditional manual navigation methods, but autonomous ships need an automatic fallback. No other technology can fully replace GNSS in all aspects, so we need to compromise on accuracy, operational area, measurement delay and/or robustness. I try to solve the problem of GNSS redundancy for the case when the ship is in vicinity of land.

Proposed solution

There are several possible solutions, but the one I pursue is radar. We can use it to keep track of land relative to the ship, and thus keep track of the motion of the ship. Will allow the ship to continue operations with increased safety margins when it loses GNSS coverage.

Main activities during 2023

- Conference paper: Maritime radar odometry inspired by visual odometry, *26th International Conference on Information Fusion (FUSION)*.
- Worked on a new maritime radar SLAM algorithm.
- Innovation pitch, SFI Days 2023.



Visualization of an estimated trajectory. The green trajectory is ground truth and the red (partly under the green) is the estimated trajectory. The blue ellipses are the tracked feature points.

Daniel Menges

Digital Twin of Autonomous Surface Vessels for Improved Situational Awareness and Optimal Control

Problem statement

This PhD project aims to tackle the following tasks:

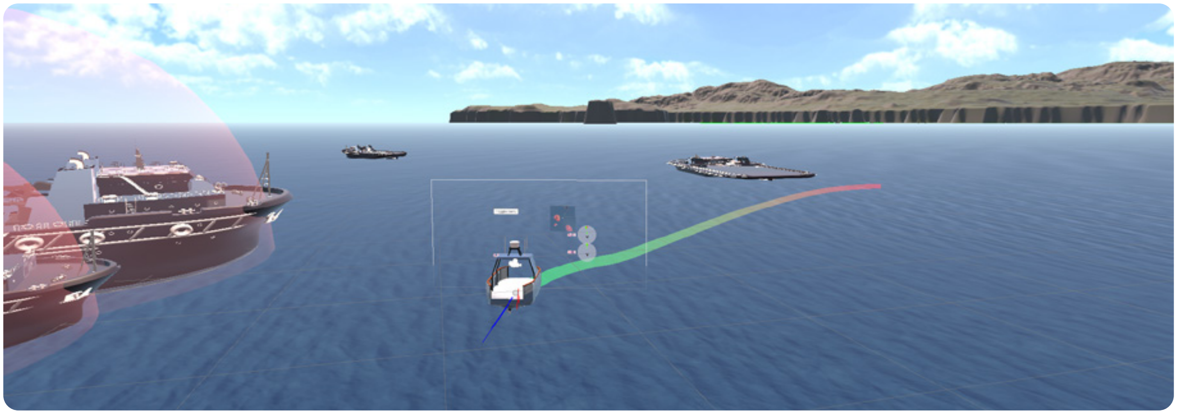
1. Estimation of environmental forces on an autonomous surface vessel impacted by wind, waves, and sea currents under consideration of measurement uncertainties.
2. Detection and prediction of anomalies in thermally stressed components of a vessel.
3. Safe navigation and control of autonomous surface vessels for collision avoidance, path following, and anti-grounding considering the impact of environmental forces.
4. Developing a digital twin for training and testing algorithms in a safe environment and extending the overall situational awareness of a real physical system.

Proposed solution

1. An environmental disturbance observer enables an accurate estimation of environmental forces impacted by wind, waves, and sea currents using velocity measurements of the vessel.
2. A predictive condition monitoring framework of a vessel's engine using thermal cameras facilitates anomaly detection capabilities to track critical outages early on. Furthermore, those anomalies can be predicted, leading to proactive awareness that can reduce operational costs since preventive maintenance can be avoided.
3. Two different optimal control approaches using reinforcement learning, predictive safety filters, and nonlinear model predictive control enable proactive collision avoidance, path following, and anti-grounding under consideration of environmental disturbances.
4. The development of a Digital Twin (DT) of an autonomous surface vessel and the Trondheim fjord using the Unity game engine demonstrates the potential of a digital representative mapping the real world through physics-based models and real-time data, including weather and AIS data.

Main activities during 2023

- Development of a predictive condition monitoring framework for a vessel's engine using thermal cameras to detect anomalies and track critical outages early on.
- Development of a computationally and memory-efficient big data workflow for predictive analytics.
- Development of optimal control approaches for proactive collision avoidance, path following, and anti-grounding under consideration of environmental disturbances.
- Articles: An environmental disturbance observer framework for autonomous surface vessels, *Ocean Engineering*, and Digital Twin for Autonomous Surface Vessels to Generate Situational Awareness, *ASME 2023*.
- SFI AutoShip webinar with NTNU and DNV on Condition Monitoring, 06.10.2023, Innovation pitch, SFI Days 2023.



Digital twin demonstration of the milliAmpere ferry on the Trondheim fjord executing the predictive safety filter to generate a safe path.

Simon J.N. Lexau

Autonomous docking of marine surface vessels

Problem statement
Autonomous docking for marine surface vessels in realistic and dynamic environments involves high-level decision making as well as low-level control systems. The existing automated docking systems are often "hard-coded", lacks robustness for unforeseen events, and only works under ideal conditions in pre-programmed harbours.

Proposed solution
High-level decision making will determine an initial path in the harbour as the ship initiates the docking procedure. A mid-level decision system will be capable of replanning the path as new information of the environment becomes available during docking. Meanwhile, the low-level control system ensures that the ship follows the planned path, even in the presence of wind, waves, and current effects.

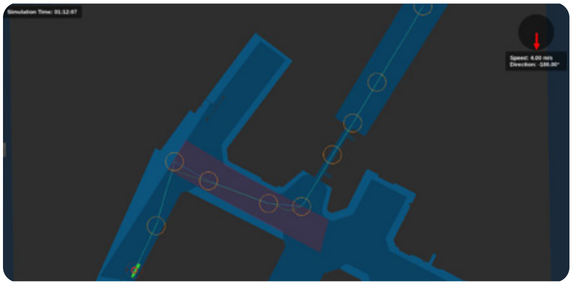
By using optimal control for all three phases, the docking trajectory can be optimized with respect to safety-distances and/or energy consumption and wear & tear.

The system can be adapted to any harbour environment, if the following information is available:

- Geographically accurate map of the harbour
  Map, need to know prior to the operation.
- Position, heading, velocity and dimensions of all moving objects in the harbour.
- AIS data, LiDAR, Radar, Cameras, needed during the operation.
- Position, heading, velocity and dimensions of the autonomous ship.
- GNSS, Gyrocompass, needed during the operation.
- A hydrodynamic model of the autonomous ship
  Obtained from System Identification (SYSID) prior to the operation.

Main activities during 2023

- Developed a real-time maritime harbor simulator with external forces, hydrodynamics, and real harbor environments.
- Published an extensive literature survey on automated docking for marine surface vessels: Automated Docking for Marine Surface Vessels - A Survey, *IEEE Access*.
- Worked on a control system for automated docking of a large Ro-Ro container vessel in the port of Antwerpen, in cooperation with Kongsberg.
- SFI AutoShip webinar with NTNU, Kongsberg Maritime and DNV on Automated docking for marine surface vessels, 18.09.2023, Innovation pitch, SFI Days 2023.



Simulated case study of a large container vessel docking in the port of Antwerp, under the influence of wind and area-specific current

Docking Characteristic Index (DCI), a metric introduced in the survey article to give a clear representation of the different challenges of automated docking. Here are the mean DCI values from each epoch discussed in the article."

Trym Tengesdal, postdoc

Simulation framework and software environment for evaluating automatic ship collision avoidance algorithms

Problem statement

Research on automatic ship collision avoidance and anti-grounding is nowadays abundant and features a rich set of proposed algorithms/systems. Despite many of these having been tested extensively in experiments, there is limited focus on systematic and extensive testing and validation also in a simulation environment. This is paramount for regulatory bodies and the public to gain trust in autonomous navigation systems and will make it easier to deploy such systems as decision support in existing vessels and as part of the autonomy suite on emerging autonomous ship technology.

Proposed solution

A tailor-made framework for simulation and evaluation of maritime vessels with an automatic collision avoidance and anti-grounding (motion planning) system. The framework can be used for verification and assurance, and further enables automatic adjustment of collision avoidance systems online or offline. It can also be used for automatic scenario search in system stress testing. The system comes with a set of standard scenarios, i.e. a benchmark, that can be used and built upon in the testing. The user can set up scenarios with grounding hazards from Electronic Navigational Charts, realistic target tracking on either intelligent or non-intelligent nearby vessels. The performance of the system can then afterwards be automatically evaluated according to the maritime traffic rules (COLREG). Any kind of motion planning algorithm can be tested, as long as the framework interface is adhered to.

Main activities during 2023

- Developed a tailor-made software environment and framework for simulation and evaluation of maritime vessels with an automatic collision avoidance and anti-grounding system. Conference paper on the framework published at *CCTA 2023*: Simulation Framework and Software Environment for Evaluating Automatic Ship Collision Avoidance Algorithms.
- Developed a method for approximating non-convex grounding hazards in the unstructured maritime environment as continuously differentiable surfaces represented by Radial Basis functions. Conference paper accepted for publication at ACC 2024.
- Developed and compared a set of Rapidly-exploring Random Tree algorithms for ship trajectory planning and behavior generation in the presence of grounding hazards, in problems of varying complexity. Journal paper submitted to Journal of Ocean Engineering: A Comparative Study of Rapidly-exploring Random Tree Algorithms Applied to Ship Trajectory Planning and Behavior Generation.
- Conference paper: Modular Collision Avoidance Using Predictive Safety Filters, *ASME 2023*.
- Journal paper submitted and accepted: Obstacle Intention Awareness in Automatic Ship Collision Avoidance: Full-Scale Experiments in Confined Waters, *Field Robotics 2024*.
- SFI AutoShip webinar with NTNU, UiO and DNV on Bridging the gap between COLREGS and algorithms for collision avoidance, 22.03.2023, Innovation pitch, SFI Days 2023.

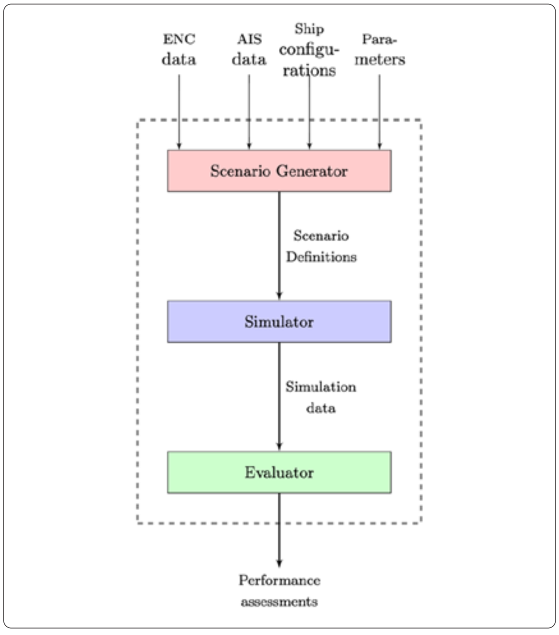


Figure 1: Framework architecture. ENC: Electronic Navigational Chart, AIS: Automatic Identification System

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 2023, a decentralized hierarchical collision avoidance algorithm was introduced for multiple ships, featuring route exchange abilities. The architecture includes mid-level and reactive trajectory planners, addressing navigational rules and static and dynamic obstacles. Furthermore, an autonomous ship trajectory planning decision support system was created, emphasizing human-machine collaboration and utilizing multi-objective optimization and multi-criteria decision-making techniques. Additionally, the radar network, consisting of a total of 4 radars, has been fully established and data from real-life experiments in the Trondheim fjord were acquired. Tracking and detection algorithms have been applied to the collected data sets.

Photo: Sander Furre

Melih Akdağ

A Decision Support System for Autonomous Ship Trajectory Planning

Problem statement

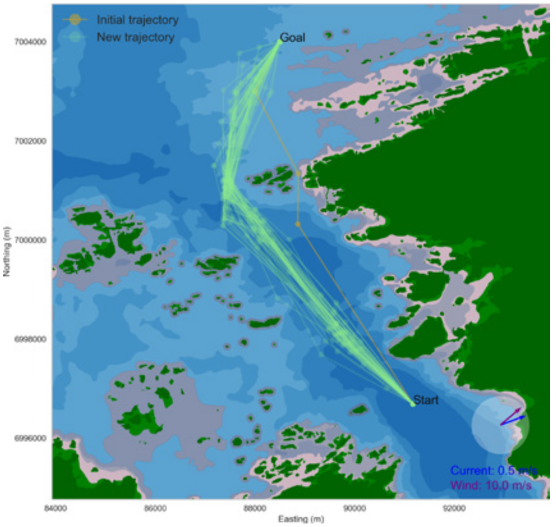
a. In what ways can autonomous ship navigation be enhanced through the integration of information about environmental forces, navigable waters, maneuvering characteristics, and potential failure modes?
b. What advantages and obstacles are associated with the utilization of a decision support system based on multi-objective optimization for autonomous ship navigation?
c. What strategies can be employed to foster collaboration between autonomous systems and operators during the decision-making process of ship navigation?

Proposed solution

a. When planning the trajectory of an autonomous ship, it is important to take into account factors beyond just chart depths. The actual depths of water can vary depending on the tide and weather conditions. High speeds in narrow channels can cause a squat effect and lead to the ship running aground in shallow areas. The ship's maneuvering abilities, such as stopping distance and turning circle, are also influenced by its speed.
b. One advantage is that a decision support system based on multi-objective optimization can treat multiple conflicting objectives independently rather than merging them into a single objective. Moreover, this method creates numerous alternate solutions, giving users a range of choices. A drawback is, solving a multi-objective optimization problem take time depending on the problem definition, algorithm, hardware systems, and especially if the dynamic obstacles' future trajectories are also considered.
c. While autonomous systems excel in speed, accuracy, and multitasking, human operators possess unique qualities such as adaptability, emotional intelligence, creativity, and ethical reasoning. Evaluating the strengths and weaknesses of each information processing capability is essential for designing effective human–machine collaboration. This research aims for human–machine collaboration by utilizing multi-objective optimization algorithms to find multiple alternative solutions meeting the objective criteria, and ranking the solutions by using the human operator preferences for each objective. Depending on the problem definition, it is experienced in this study that some solutions came up high in the ranking although they are not preferable by the authors. This serves as a valuable reminder to not solely depend on solutions suggested by autonomous systems, but to also involve human evaluation.

Main activities during 2023

- A decentralized hierarchical collision avoidance algorithm was introduced for multiple ships, featuring route exchange abilities. The architecture includes mid-level proactive and reactive trajectory planners, addressing navigational rules, static and dynamic obstacles.
- An autonomous ship trajectory planning decision support system was created, emphasizing human-machine collaboration and utilizing multi-objective optimization and multi-criteria decision-making techniques. The system considers ocean currents, wind, and tidal information, alongside the integration of narrow channel geometry, squat effect, Under-keel-clearance (UKC) and the Dynamic Consequence Analysis (DCA) risk assessment methods.
- SFI AutoShip webinar with NTNU, UiO and DNV on Bridging the gap between COLREGS and algorithms for collision avoidance, 22.03.2023, Innovation pitch, Ocean Week 2023.



Alternative trajectories calculated by the proposed decision support system.

Lukas Herrmann

Shore-based Radar Network for Autonomous Shipping

Problem statement

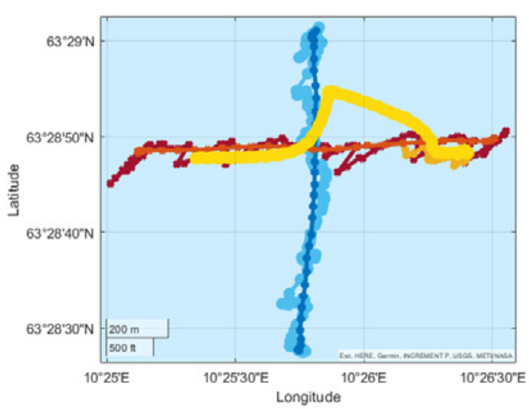
During the last years, the idea of autonomous shipping has become more and more concrete since autonomy has the potential to revolutionise this industry by enhancing safety, speed, reliability, sustainability, efficiency, and ultimately cost optimisation. For the whole concept to work it is crucial for every vessel to know where it is and where all the other vessels are to avoid collisions and enable optimal path planning. To realise the full potential of autonomous operations, every vessel needs to possess this comprehensive situational awareness. This becomes particularly interesting in the harbour and close-to-shore areas because they are busier, and all types of vessels can appear such as smaller boats or even kayaks. The driving forces when it comes to autonomy are sensors and algorithms. However, not all vessels are equipped with sensors or enough of them. This can be due to various reasons. Sensors are expensive, they take up space, they require special knowledge, and sometimes they are just not accurate enough.

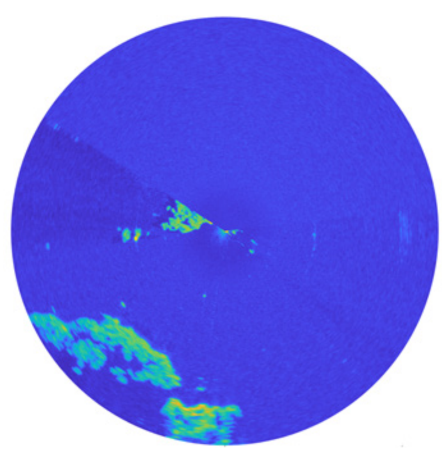
Proposed solution

I am developing a shore-based radar network, consisting of several radars at multiple sites which will detect vessels within the observed area and can distribute the position information of all the tracked targets. The hardware of the system I am using on land is a lot more powerful than any standard hardware on ships at the moment and is in addition combined with complex algorithms that I am developing.

Main activities during 2023

- Establishment of the radar network consisting of 4 radars located at two different sites.
- Developing solutions for digitising and recording radar raw data.
- Data acquisition of real-life experiments in the Trondheim fjord.
- Development and implementation of detection and tracking algorithms on both simulated and real data.
- Conference paper: Histogram-probabilistic multi-hypothesis tracking with a Poisson mixture measurement process, *Proceedings of SPIE, the International Society for Optical Engineering*.
- Innovation pitch, SFI Days, 2023.





Radar target tracking results vs GNSS ground truth (left), and a single radar image observing the fjord (right).

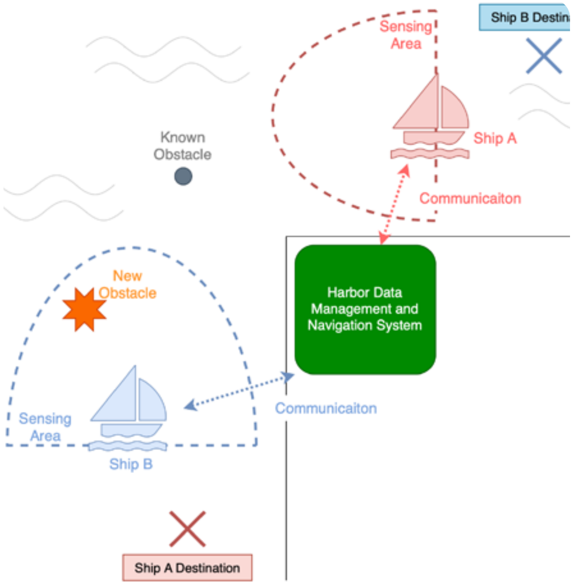
Peter Morris

Data Fusion in Maritime IoT

Background including motivation for the research
Maritime transport is set for significant transformation in the coming years; automation, artificial intelligence, unmanned vehicles, and other new technologies are poised to drastically change the everyday workings of vessels and harbors. This project aims to provide a base and framework for unmanned maritime vessels to address the distinct navigation and awareness challenges they will face.

Objective and main tasks
Carrying out this project will start with a comprehensive data aggregation system, for collecting heterogeneous types of data from multiple sources. The approach for this will be to use various open source tools to build a maritime IoT & cloud platform. Then, using the gathered data, the project can then build out a real-time environmental surveying and mapping system. There are a variety of persistent SLAM-style techniques applicable to this topic. Finally, this mapping of landmarks and obstacles can then be combined with positional data to create a routing system for the vessels. This routing system can be created through use of machine learning analyzing various simulations, with a particular focus on uncertainty, and emergent obstacles and vessels.

Expected results and innovations
The hopeful results of this project will be a heterogeneous data fusion platform for maritime use, a collaborative maritime real-time mapping system, and complementary route planning for multiple marine vehicles. These tools will be used in concert to enhance each other. Expected innovations embedded in these results are planned to be in the areas of incorporating various forms of machine learning, handling and addressing uncertainty across many variables, including humans in the loop for navigation and landmarking concerns, and more. A perfect version of this system would provide a fully orchestrated harbor and vessel direction system that accounts for real-time changes in environment and deviations form charted courses.



An illustration of the problem this project addresses. Solving this issue requires gathering data, using the data to map the environment, and using the environment and positional data to chart navigation routes.

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.

Our objective is to develop safe and efficient human-machine interfaces and interaction for remote operation centres (ROCs).

In 2023 Work Package 3 has published more than 10 papers, carried out more than 50 popular science dissemination activities, and submitted two DOFIs and a patent application. All these activities have contributed to reaching the Centre's objectives in 2023.

The control room at the NTNU Shore Control Lab where two operators monitor an autonomous ferry operation with multiple vessels.
Photo: Jooyoung Park/NTNU

Andreas Nygard Madsen

AI Decision Transparency

Problem statement

- How can we make the decisions or suggestions from an AI system transparent to a navigator?
- How can collaboration between the navigator and the system help to enhance and maintain situational awareness?
- What is required (from a human factor perspective) when operating with a periodically un-manned bridge?

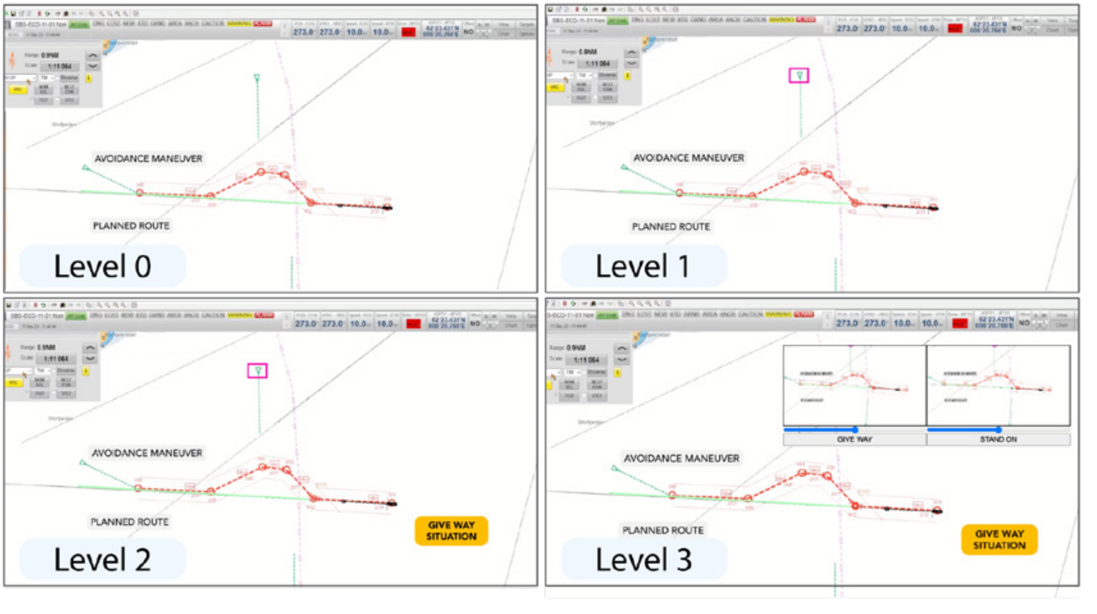
Proposed solution

Strategies for AI decision transparency and guidelines for the human-machine collaboration in collision avoidance situations:

- Assess the compatibility of human- machine interaction in full mission simulators.
- Layered approach to transparency visualization for collision avoidance.
- Take into account seamanship when creating AI for collision avoidance. Periodically un-manned bridge is currently on-going research.

Main activities during 2023

- Conducted a simulator study on human-AI interaction with regards to collision avoidance, presented at the AHFE conference in San Francisco and published in *Human Factors in Robots, Drones and Unmanned Systems*: Decision Transparency for enhanced human-machine collaboration for autonomous ships.
- Published opinion-piece in Skipsrevyen: Selvkjørende ferjer er ikke lik «ingen mennesker», May 2023.
- Simulator study testing automation transparency true VHF-radio, scientific paper in review.
- Planned simulator study for testing a layered approach to AI decision transparency in collaboration with DNV.
- Collaborated with SINTEF, IFE, Kongsberg Maritime, Grieg, and UiO on an approach to periodically un-manned bridge (B-0).
- Contributed to development of a Maritime Head-up display, resulting in a DOFI and patent application.
- Innovation pitch, SFI Days 2023.



Protoype of transparency layers on ECDIS. Conceptualization by Andreas Madsen NTNU Ålesund. Design Jooyoung Park NTNU, Shore Control Lab

Felix-Marcel Petermann

Investigating New Solutions for Situational Awareness in Autonomous Passenger Ferries

Problem statement
In the advancement of highly automated or autonomous ships, there is a notable reduction in onboard personnel. This shift requires improved management of alarms. Furthermore, as operations increasingly transition to remote operation centres and shore-based operators, vital information traditionally available to onboard operators—such as vessel tilt, rolling, wind sounds, engine vibrations, alarms, and environmental cues like smells and visual observations—are now consolidated remotely. These elements are crucial for maintaining proper situational awareness and ensuring the safe operation of a vessel.

Presently, the conventional approach involves displaying some of this information on screens. However, human operators engage with more than just visual data displayed on screens; they draw upon various forms of knowledge, including explicit, implicit, and pictorial knowledge, which are integral to their operational effectiveness.

Proposed solution
The solution employs a variety of modalities to enhance situational awareness for operators both on ship bridges and in control rooms. Traditional alarm systems, characterized by standard beeping sounds lacking informative value, are replaced with voice command augmented alarms, facilitating clearer communication of critical information. Additionally, innovative technologies are leveraged to simplify complex data into easily understandable interfaces. Spatial sound technology enriches auditory cues by providing directional information, directing operator attention effectively. Furthermore, movement platforms and vibratory engines are integrated to convey tactile feedback to control room operators, enhancing their understanding of dynamic situations.

Moreover, the solution incorporates expansive camera views, extending up to 360 degrees, to afford operators a comprehensive perspective of their surroundings.

Main activities during 2023
- Several dissemination activities, including midterm presentation, presentations of the Shore Control Lab, and paper presentation on Explanatory Interfaces at IHSI in Venice.
- Progress and Analysis from the 2022 Trial of Autonomous Passenger Ferry are underway, with several publications in the pipeline.
- Completion of coursework in "Advanced EEG Analysis" and "Topics in Design Research" by 2023.
- SFI AutoShip webinar on Remote Control Rooms, 14.11.2023, Innovation pitch, SFI Days 2023

Concept of a new operator station.

Luka Grgčević

Vessel guidance decision support systems

Problem statement
The research will tackle the problem of balance between good seamanship and control effort by designing new decision support algorithms for vessel guidance for multi-vessel scenarios. Tailoring different reward functions to minimize the risk of a guidance strategy applied is important in its justification during remote operations or in Human-Machine Interfaces on board or the shore. We are making an agent-based application with models of the own and target vessels in which we currently train agents and test different scenarios.

Proposed solution
We designed three types of rewards with which we train the agents to find the strategy for a given time horizon and a traffic situation:

- Dynamic and static obstacle global collision risk metric.
- Trajectory tracking cost.
- COLREG compliance cost.

Main activities during 2023

- Analysis of multi-vessel encounters in high-density vessel traffic
- Synthesis of decision support algorithms for vessel guidance
- Multi-agent simulations utilizing game theory and reinforcement learning
- Submitted conference paper: “Towards Decision Support in Vessel Guidance Using Multi-agent Modelling” for the European Control Conference (ECC24), Sweden.
- Innovation pitch, SFI Days 2023

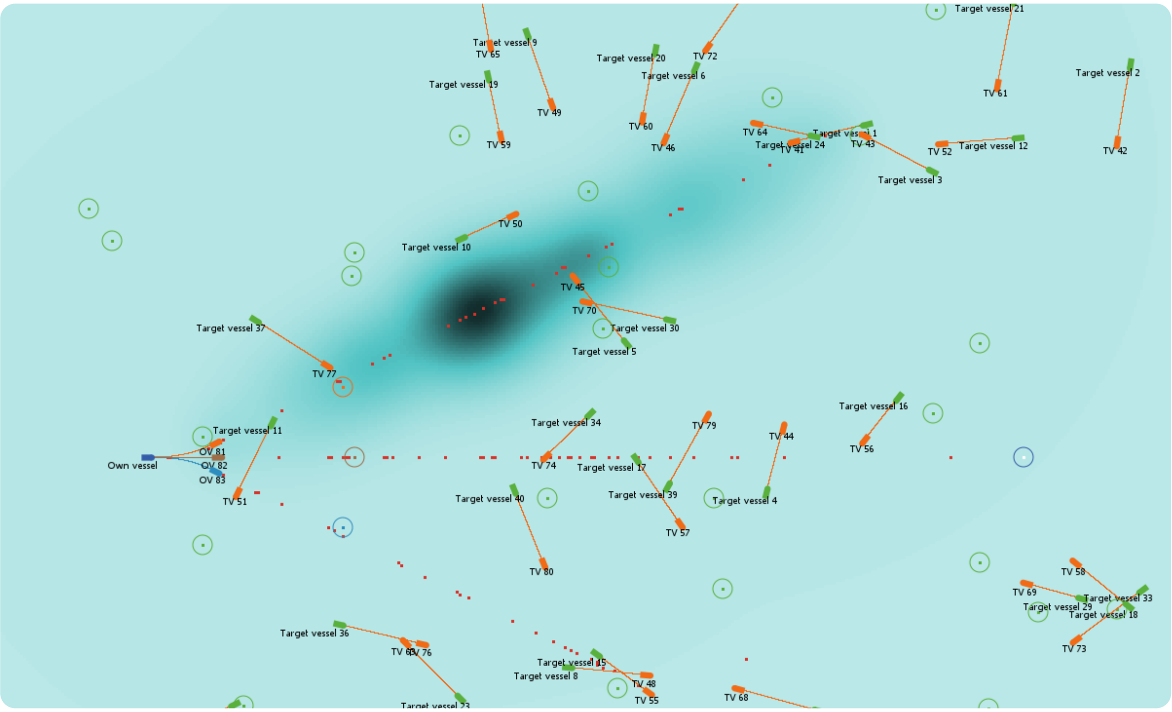


Fig. 1 An example of a traffic scenario for designed guidance algorithm verification. Own ship in blue chooses a series of actions by which it attempts to minimize the plotted global collision risk metric together with trajectory tracking cost and COLREG compliance cost.

Taufik Akbar Sitompul, postdoc

OpenCrane Design System

Problem statement

Currently, crane manufacturers and third-party suppliers create their own user interfaces (UIs), since there are still no standardized UIs for operating cranes. This situation leads to significantly different UIs even for the same type of cranes. The significantly diverse UIs also pose two major challenges. Firstly, the cost for developing user interfaces is high, since crane manufacturers and third-party suppliers must develop everything from scratch and perform evaluations on their UIs. Secondly, operators need to train themselves every time they utilize UIs from different crane manufactures or third-party suppliers. Using significantly different UIs may also increase the risk of human error, since different UIs may have different rules or mechanisms that operators should follow.

Proposed solution

To improve the design consistency across UIs from different crane manufacturers and third-party suppliers, there is a need for a design system that crane manufacturers and third-party suppliers can use or refer to when developing their own UIs. OpenCrane Design System offers open-source UI elements for operating cranes that everyone could use, adapt, and distribute.

Main activities during 2023

- Focused on developing OpenCrane Design System, which is an open-source design system for building user interfaces for operating cranes.
- For the first version of OpenCrane, Taufik successfully designed and evaluated user interface components for remotely operated ship-to-shore (STS) and rubber-tired gantry (RTG) cranes.
- In addition, Taufik also designed and evaluated graphical information that could help operators control their cranes remotely in the presence of high latency.
- Conference papers: Designing User Interface Elements for Remotely Operated Rubber-tired Gantry Cranes published at *IEEE SMC 2023*, and both “Designing User Interface Elements for Remotely Operated Ship-to-shore Cranes” and “Evaluating Graphical User Interfaces for Handling Latency in Remote Crane Operation” published at *BCS HCI 2023*.
- SFI AutoShip webinar on Remote Control Rooms, 14.11.2023, Innovation pitches at Ocean Week and SFI Days 2023.

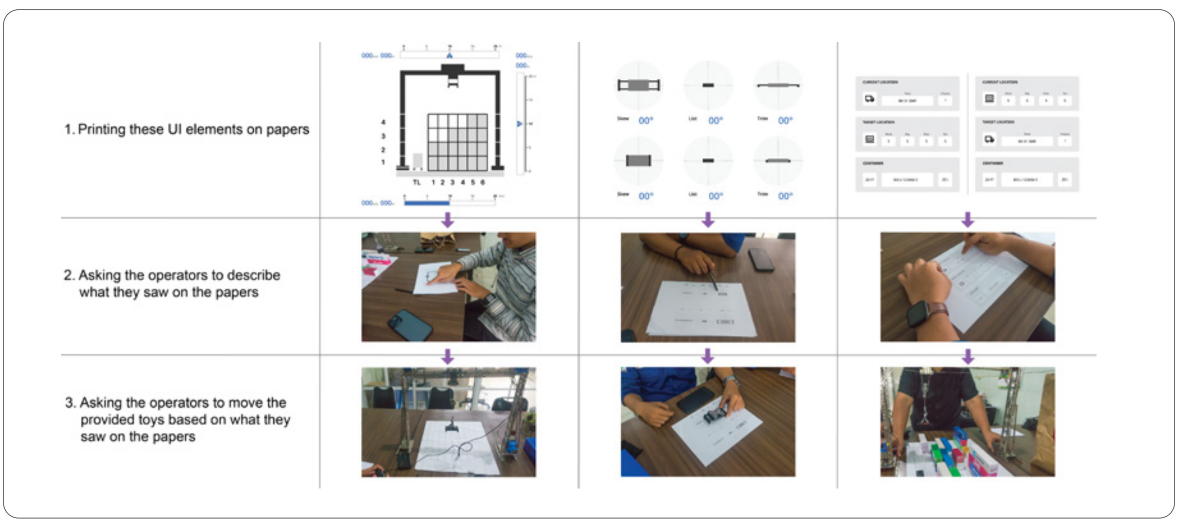


Figure 1. The images that visualize how the UI elements in OpenCrane Design System were evaluated with crane operators.

Eirik Fagerhaug

Explainable AI for Autonomous Ships

Problem statement

The project aims to address some issues related to data management in autonomous maritime operations. There is a need to effectively handle and interpret a very large and diverse collection of data, this includes publicly available information, such as weather conditions and details about coastal facilities, but also specialized data generated by the ships themselves and various onshore installations such as Remote Operating Centers, coastal sensor arrays, and Vessel Control Centers.

The core issue stems from the requirement to integrate and understand these varied data streams in real-time, ensuring that both machines (for operational efficiency and decision-making) and humans (for oversight, intervention, and understanding) can make sense of the information.

Proposed solution

The solution our project has developed is a data model that uses spatial graphs or networks to enhance data integration and accessibility. This model organizes data in a way that emphasizes the connections and relationships between different data points, and with tools that can be used for better visualization and comprehension. It's designed to serve as a foundation for both AI training and data analysis, supporting the development of AI models with a focus on explainability for operators at remote operating centers.

Main activities during 2023

- Research and development on a graph-based platform to be used as a basis for maritime AI navigation
- Participated in the Nordic Seminar on eXplainable AI (XAI) 29-30 March
- Completed courses: EECI IGSC2023 M14 Paris-Saclay (Course: Introduction to Nonlinear Systems & Control) and EECI IGSC2023 M21 Bologna (Course: Distributed optimization for cooperative robotics and decision making: theory, numerical methods and toolboxes)
- Co-authored Predictive digital twins for autonomous surface vessels, *Ocean Engineering* and Predictive Digital Twins for Autonomous Ships, *Proceedings of the 2023 IEEE Conference on Control Technology and Applications (CCTA)*

Representation of a graph-based platform for AI based navigation. Illustrations generated by DALL-E.

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. Since 2021, we have consolidated the work of the PhDs and postdoc and conducted webinars together with industry related to topics on Risk of Autonomous Ships, hosted by NTNU.

Photo: Photo: Trond Johnsen/SINTEF

Susanna Dybwad Kristensen

Online risk modeling of autonomous ships

Problem statement
Autonomous ships may operate independently from human operators. This means that the autonomous system itself must be capable of monitoring and assessing the risk related to the operation it is performing, to make decisions for safe and efficient operations. Using risk models to provide information to the autonomous system during operation can be a solution to this. However, a condition for this is that the risk information that is provided from the risk model is suitable for supporting the decision the autonomous system is making.

Proposed solution
A solution to this can be to test how different formulations of risk through risk metrics can be integrated with the autonomous system, and how this affects the decisions made by the system. The same online risk model is used in a scenario, but the risk is formulated using different risk metrics. This may influence the decisions made by the autonomous system. By observing these decisions in simulation and in experimental field trials, the effect of using different risk metrics for decision-making is observed, and the results may contribute to providing a foundation for selecting suitable risk metrics in the future.

Main activities during 2023
- Development of an online risk model for supporting decision-making by an autonomous surface vehicle cooperating with an autonomous underwater vehicle.
- Planning and execution of experimental field trials with an autonomous surface vehicle, the Grethe ASV from the AURLab at NTNU, in the Trondheimsfjord, Norway. The purpose of the trials was to test the use of the risk model and to test how using different risk metrics affects autonomous system decision-making.
- Co-authored journal paper Risk-based path planning for preventing collisions and groundings of maritime autonomous surface ships in *Ocean Engineering*.
- Participated in meetings with the partners in Use case 4 in Haugesund, Norway and in Nootdorp, the Netherlands.
- Innovation pitch, Ocean Week 2023.

Figure 1 The Grehte ASV used for field trials in the spring of 2023. The trials were used to test the effect of using risk information for decision-making under real operating conditions.

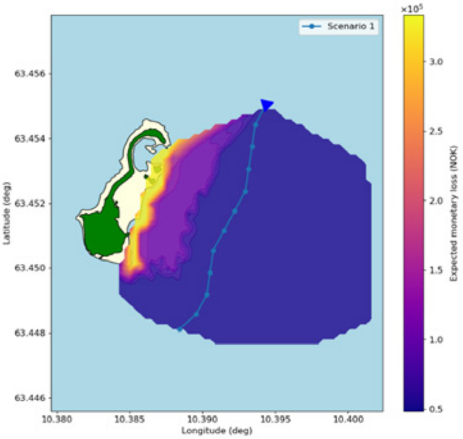


Figure 2 Integrating risk models with path planning. Example of how the autonomous surface vehicle can perceive risk based on information from an online risk model when planning a path close to Munkholmen Island, in the Trondheimsfjord, Norway.

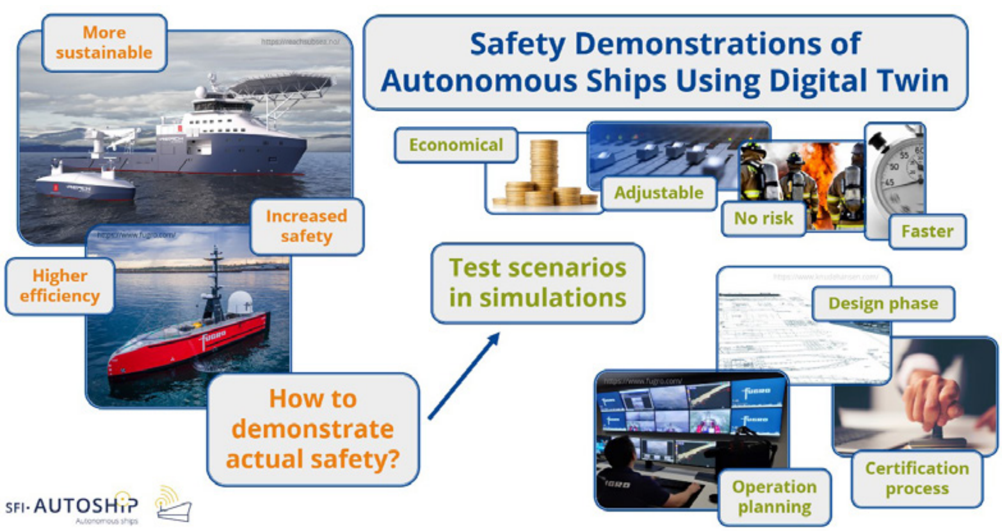
Raffael Wallner

Safety Demonstration of Autonomously Controlled Ships using Digital Twin

Problem statement
The maritime industry is about to revolutionize, with highly automated or autonomous ships promising to make sea transport more efficient, sustainable, and safe. However, such new and highly automated or autonomous systems are complex and difficult to comprehend, making it challenging to test and prove their safety with current methods. This poses a significant barrier to the adoption of such technologies and needs to be resolved to boost the growth of the Norwegian maritime cluster.

Proposed solution
The research on Safety Demonstration of Autonomously Controlled Ships using Digital Twin proposes a novel solution to this problem. The methodology involves scenario-based testing in simulations. In this approach, the system or system components and the operational environment are modelled in a virtual environment utilizing digital twins to achieve valid representations and connections to real control units. This allows the tested system to be exposed to any arbitrary situation it may encounter during operation, all within a risk-free simulated environment. This comprehensive testing approach can demonstrate that the overall system operates safely in a representative set of scenarios, covering the whole operational space from normal operation to risky situations and even beyond that. That way it can be used for design verification, during certification procedures, and to support operation planning.

Main activities during 2023
- Presentation and publication of paper: Identification of Test Scenarios using STPA and CAST at *ESREL 2023* in Southampton
- Organization of an STPA workshop with participants from several SFI partners
- Working on simulated safety demonstrations of a small-scale crane in collaboration with IFE
- Partner visits/facility tours and meetings at NMA and Reach Subsea in Haugesund and at Fugro in the Netherlands
- Innovation pitches at Ocean Week and SFI Days 2023



Spencer A. Dugan

Reliable design and operation of propulsion systems for autonomous ships

Problem statement

The widespread introduction of autonomous ships is still limited by RAMS related issues. There are several differences in the operation of machinery systems when compared to conventional ships – most notably prognostics, maintenance scheduling, and repairability. The thesis focuses on losses of command, i.e., a failure of the propulsion, electrical generation, or electrical distribution systems. This type of failure can lead to serious consequences if command is not restored, or appropriate mitigation actions do not occur.

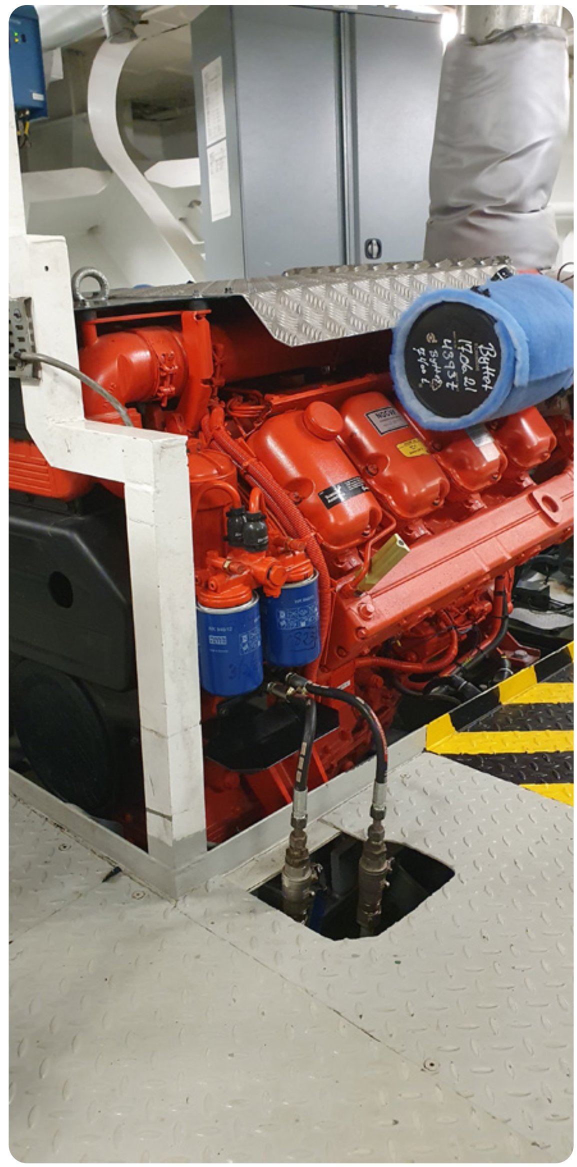
Furthermore, novel machinery configurations, often introduced for decarbonization or operational efficiency, are increasingly interdependent; equipment for power generation and distribution require auxiliary systems, yet these auxiliaries are dependent on power to operate. This tanging and nesting of systems increases the susceptibility to both cascading and common-cause failures.

Proposed solution

The first phase of the work has focused on establishing failure rates for losses of command failures occur and identifying factors associated with their occurrence. The second phase focuses on design solutions for the preliminary ship design stage and risk-based operational guidelines to reduce the frequency of this failure mode and consequence mitigation. Design solutions include machinery topology evaluation and redundancy allocation for auxiliary systems. Operational guidance are risk-based modifications to the power management system, e.g., start-stop of generators and intelligent load shedding.

Main activities during 2023

- Submitted journal article Statistical analysis of vessel loss of command frequency in *Maritime Transport Research*, published February 2024.
- Conference paper and presentation: Evaluating differences between maritime accident databases, *Proceedings of the 33rd European Safety and Reliability Conference (ESREL 2023)*.
- SFI AutoShip webinar with Torghatten on Safety and reliability of machinery systems, 11.12.2023, Innovation pitch, SFI Days, 2023.



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

Ayoub Tailoussane

The Application of the COLREGS to Autonomous Vessels: A potential solution to the legal challenges

Problem statement

The goal of the research is to see how autonomous vessels can be integrated into the framework of the regulations for collision prevention without or with very minimal amendments.

Proposed solution

Autonomous vessels must be distinguished from conventional vessels. It is important to recognize that many aspects of the collision regulations (COLREGS) cannot be fully complied with by autonomous vessels. Therefore, it is proposed that autonomous vessels be required to follow only a limited/specific part of the COLREGS in order to reduce the number of legal barriers and facilitate/support the development of autonomous navigation systems that are, not just compliant, but actually safe.

Main activities during 2023

- Successfully completed the mid-way assessment of the PhD project.
- Gave a presentation on the project at the Oslo – Tulane – Southampton Maritime Law Colloquium in New Orleans, USA.
- Finished writing 40 – 50% of the thesis, which was focused on two major goals: (i) To propose a legal definition of "autonomous vessels" and (ii) to provide an in-depth legal analysis of a small selection of rules in order to show why it is difficult, if not impossible, to transform certain rules of the COLREGS into machine-executable algorithms.
- Started researching and outlining some preliminary answers to the next big question of the thesis: Can COLREGS-compliance be achieved without human sight?
- Started collaborating with the other participants in Use-Case 1 on the Bridge Zero Project.
- SFI AutoShip webinar with NTNU, UiO and DNV on Bridging the gap between COLREGS and algorithms for collision avoidance, 22.03.2023.

Illustration: Colourbox

Emir Cem Gezer

Risk-aware and safeguarding control for autonomous ships

Background and Research Motivation

The maritime industry is shifting its attention to autonomous vessels to deliver on the premise of being more efficient, safe, resilient, and reliable in a wide-ranging operation envelope. For that, it is crucial to design vessel control systems that can react and adapt to ever-changing external and internal environmental factors, and understanding the coupling between ship systems enables us to design risk-aware & safeguarding marine control systems. This research aims to address safety by exploring behavior-based vessel control design strategies and formulating risk-based operational modes.

Objective and Main Tasks

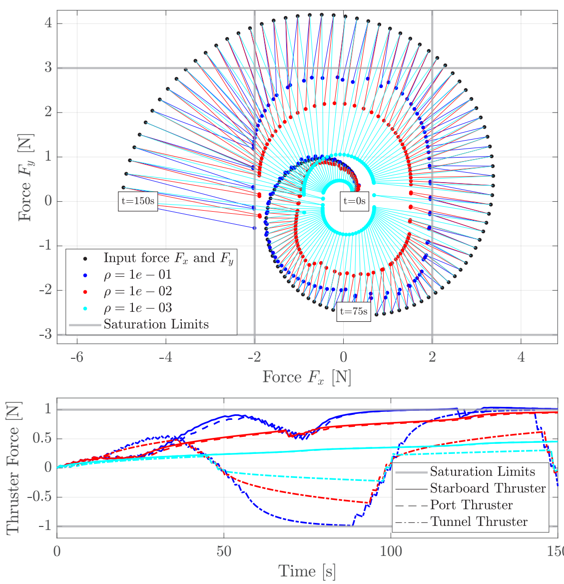
The PhD work aims to research and develop risk-aware safeguarding vessel controllers. This study focuses on topological abstraction of the ship systems, nonlinear control theories, functional coupling between different components of the autonomous system in all layers, and autonomous ship control systems. It involves implementing safeguarding strategies, formulating minimal risk conditions, and developing nominal modes. The goal is to design a mode-based control architecture that can safely and effectively switch between operational modes in response to risk factors and the vessel's mission.

Research Approach/Methodology

This study examines how control modes, risk contingency strategies, and high-level vessel operation can safely link. The process entails defining nominal operating modes, creating protective control functions, and analyzing the topological abstraction of an autonomous ship control system. Additionally, it includes the formulation of minimum risk conditions (MRCs) and the design of algorithms for entering MRC modes. The study integrates theories from Lyapunov-based nonlinear control, control barrier functions, hybrid dynamical systems, risk-aware control, numerical optimization, and switching control structures to develop a mode-oriented control architecture.

Expected Results and Innovations

The goal of this research is to improve the effectiveness and safety of autonomous ship control systems by providing new approaches for designing controllers that can allow seamless operation mode switching and new decision-making tools to choose safeguarding behaviors.



Preliminary results from an ongoing work on safeguarding thrust allocation application.

Sreekant Sreedharan

Safety assessment and verification of collision avoidance algorithms for autonomous ships

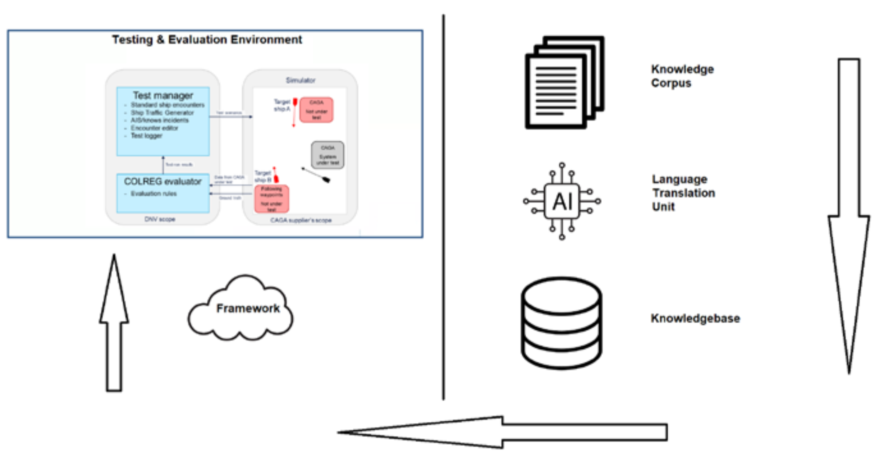
Project Synopsis

Whereas we have sufficient experience developing test tools for algorithmic validation (functional testing), the significant challenge in COLREG validation is understanding the language of COLREG itself. Given recent advances in generative AI, particularly the impressive capabilities of language models to a) understand text and b) synthesize human-like (planned & detailed) responses, its application to COLREG validation warrants an assessment.

We propose collaborating with experts in the space (COLREG & GenAI) to come together and explore the feasibility of developing a small language model (SLM), specific to maritime practice, with specific applications in software verification of ASV algorithms. Once developed, the maritime SLM, will be employed in an evaluation and verification platform.

Central to the system is 1) a conceptual framework and 2) a knowledgebase. Whereas the knowledgebase captures two things about a domain: characteristics (eg: properties of the environment) and behaviour (what can be done with the environment); the framework mediates the interpretation of the knowledgebase for testing purposes - in effect synthesizing test scenarios given a set of observed environmental properties, in real-time.

Today, all of this is codified into the COLREG evaluator as individual test cases. Implicit in the test cases is knowledge - both domain characteristics and behaviour. It is expected that by externalizing this knowledge into a repository, we allow the it to grow and be enriched by a variety of sources and/or algorithmic techniques. A core portion of the knowledge (representing immutable laws and facts about the environment) will be hand-coded by using a declarative programming language; whereas, more abstract concepts (eg: “ample time” and “good seamanship”) will be codified automatically by learning from the ‘physical world’. This allowing for the accrual of maritime knowledge incrementally in learning stages. The latter form of ‘physical learning’ will employ LTU - (language translation unit, using generative AI) to extract concepts embedded in a large (corpus of documents (legal, policy, best-practice etc.) - thus extracting characteristic and behaviour of abstract concepts from them. Conclusively, a verification framework uses concepts from the knowledgebase to synthesize test scenarios in real-time and in response to sensory & state information from the test environment, exercises algorithms to a wider range of operating conditions to ensure safety and reliability.



Alojz Gomola, postdoc

Risk role in autonomous ship software systems

Dr. Gomola was a postdoctoral fellow from July 2021-June 2023. He worked on identifying and classifying risks in autonomous ship´s software systems. Dr. Gomola´s research motivation was 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 increased 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.

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.

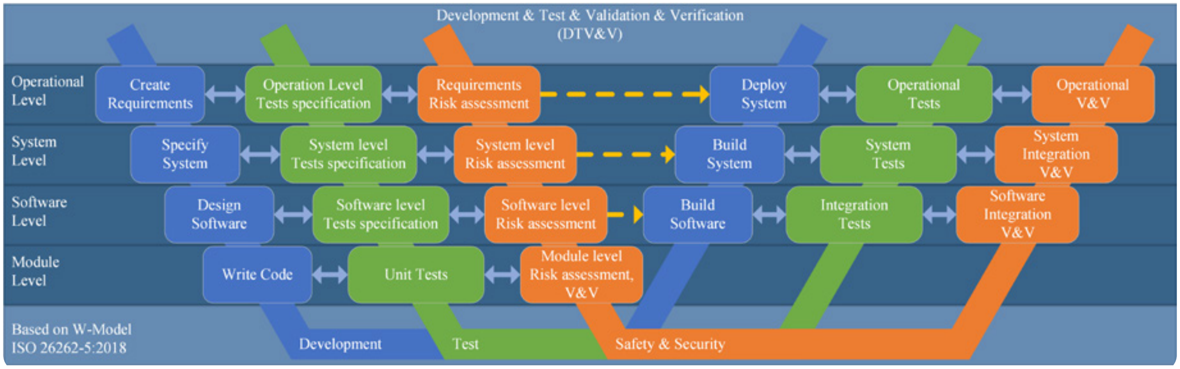
The mechanism of software failure focused on cascading propagation through multiple hardware and software systems, including human-operator interaction, has been identified. Software failure can lead to a catastrophic chain of events and significant property and human life losses.

The "Systems Theoretic Process Analysis" risk and hazard identification method is modified to cover software failure phenomena. The extension uses existing software modeling and management processes and techniques.

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.

These works have been submitted to scientific journals.

Use-case involvement and industry collaboration
Use case 3: Autonomous Ferries; one case study was executed in collaboration with Kongsberg on software failure prevention by design by application of STPA SW-SAF-SEC method.



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

5 Sustainable Operations

WP Leader: Senior project manager Odd Erik Mørkrid, SINTEF Ocean

Our objective is to develop the next generation cost-effective and environmentally friendly waterborne transport system.

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. Therefore, this work package works primarily within three axes: Logistics system cost-benefit assessments, assessment of technology and solutions for environmentally friendly operation of (periodically) unmanned ships, and optimisation of automatic control of mooring and cargo-handling systems to automate port operations.

In 2023 the work package worked on several topics related to the feasibility studies that were done in 2021 and 2022, both for uncrewed ships and automated mooring systems. Two main activities were initiated in 2023, remote operation of deck cranes for container ships and periodically unmanned bridge for deep-sea bulk ships. However, additional study was done early in 2023, together with NTNU (WP3) and Torghatten on autonomous loading and offloading of cars on passenger car ferries. This study concluded with a proposal based on traffic lights for guiding the cars to the right lanes and spots on board the ferry.

For logistics system cost-benefit analysis, there was limited work in 2023, but the planned work is based on results and findings from the EU projects AEGIS and AUTOSHIP, with corresponding KPIs. Some specific SFI Autoship KPIs have been included and the plan is to perform studies for use case 2 (short-sea container shipping) in 2024, utilising the SINTEF tool SIMPACT.

The study on periodically unmanned bridge activity has been initiated as part of the green ship initiative, and this work has been performed together with Grieg Star, Kongsberg Maritime, NTNU and IFE. Technical, regulatory and human machine collaboration have all been discussed in 2023, and the conclusion of the initial assessments concluded that there will be focus on the human role in 2024, where simulation studies will be done to clarify the situational awareness needs and reaction times related to warning and alarming from the system with respect to potential take-over by humans in critical situations.

The last work package initiative, optimisation of automatic control of cargo-handling systems, was focusing on deck cranes in 2023. Discussions with NCL and MacGregor concluded with a stepwise approach where semi-autonomous control is the most realistic on short- and medium term. The focus is on moving the crane operator from the crane to a shore-based operations center, where one operator should operate two cranes in parallel. This work is a collaboration between SINTEF, NTNU, NCL and MacGregor. The pre-study done in 2023 concluded in two main directions for 2024: How to operate a crane remotely with semi-autonomous moves, and how one operator can do parallel lifting with two deck cranes.

Lastly, the work package further delivered three papers based on the feasibility study on unmanned cargo ships, automated mooring gap study and the work related to the cargo handling automation gap analysis. In addition, a report on feasibility study for an unmanned passenger car ferry was produced.

Figure 1: The NCL newbuilds to be delivered in 2024/2025. Both have two deck cranes. Source: NCL

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. 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.

In 2023, there has been research activities and deliverables directly or in-directly related to all use cases, of which the highlights were presented at the SFI Days in October 2023. Researcher site visits to Reach (Haugesund) and Fugro (Nootdorp and Aberdeen) have been facilitated to establish connections between researchers and these newest industry partners also.

Photo: Piotr Lewandowski/G2Ocean

Use Case 1: Deep-sea bulk shipping
This use case is led by 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 North Sea Container Line (NCL). Cargo handling is the most challenging part of 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. 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.

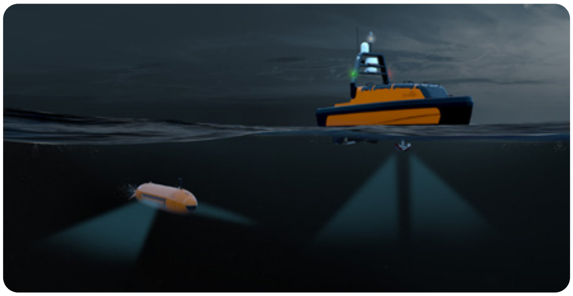


Illustration: Kongsberg Maritime

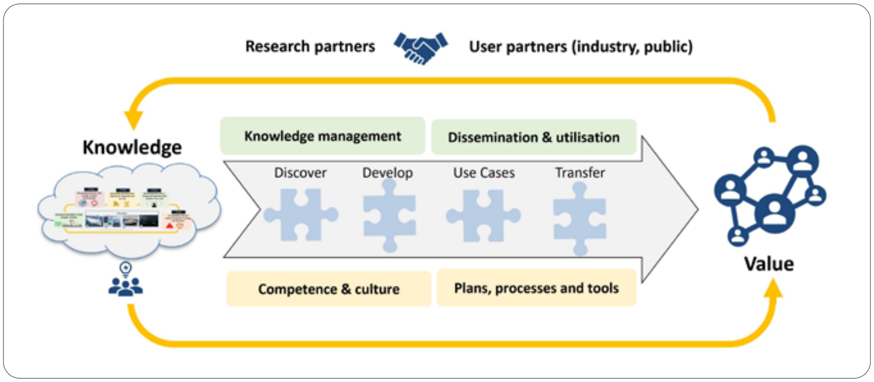
Use Case 4: Offshore support operations
This use case is led by Equinor. Research focus will be on using unmanned support vessels (USVs) in combination with autonomous underwater vehicles (AUVs) or remotely operated vehicles (ROVs) to perform inspection and maintenance operations offshore. These operations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

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 focus has been to strengthen knowledge of innovation processes and tools through network activities between the partners and with a particular attention to the PhD/PDs. Now as research activities have gained momentum, the focus on identifying value from the research and opportunities for knowledge transfer is strengthened. Activities in the work package has increased in 2023, and additional information is provided in the Highlights section of this report.



Main elements of the SFI Autoship innovation strategy.

Highlights from 2023

Innovation efforts

A key goal for the SFI is to enable innovations among consortium partners by providing new opportunities through knowledge and technology transfer based on the Centre's research activities. The research activities in the SFI are fully mobilized, and as a consequence activity related to organization and facilitation of knowledge transfer has intensified in 2023.

Focus on training of researchers and facilitating ideation
Two innovation workshops for researchers have been carried out during the year. Objectives for the workshops were to provide insight in innovation theory, and to engage participants in discussions on aspects of technology transfer and research-based value creation.

A workshop for the PhDs and PDs in SFI AutoShip was organised in March 2023. The workshop was planned in cooperation with resources from SFU Engage (NTNU Centre for entrepreneurship). SFU Engage also provided resources for the execution of the workshop. The objective of the workshop was to raise the awareness of own role in contributing to realisation of value of the research and assist in developing a first minimum value proposal. Outcomes of the workshops are defined innovation leads from the various research activities and short presentations by the researchers that later were given at NTNUs Ocean Week and for the Centre partners at the SFI Days.

In December a follow-up was conducted revisiting the topics from the first workshop, including this time an introduction to commercialisation of research by NTNUs Technology Transfer Office.

Focus on knowledge transfer
Successful utilization of the results from research implies turning scientific results and prototypes into sustainable, user optimised, ready for use applications and services. Depending on the results considered, the results will be exploited at different levels: scientific exploitation (further research), commercial exploitation (knowledge transfer) or open-source exploitation. Utilisation of research results from SFI Autoship will take place outside the boundaries and activities defined by and included in SFI Autoship. A key topic for the innovation and commercialisation committee's work in 2023 was to establish the first version of the SFI AutoShip exploitation plan. The plan defines the framework for management of intellectual property and knowledge transfer and is a dynamic document subject to revisions as research results mature. As a part of the exploitation plan, value proposals as developed through the innovation workshops are structured and provide input an overview of the status of the research for the consortium partners.

Focus on innovation competence
A SFI represents a valuable opportunity to further strengthen the competence on innovation and innovation related competence. In SFI Autoship this opportunity is pursued partly by collaboration with other research centres and partly by own follow-on research.

Centres for research-based innovation, such as SFI AutoShip, represent an important contribution to increase innovations for the participants involved, and sharing of experience and knowledge represents an important part of the contribution. In a collaborative effort by 8 SFI centres hosted by either NTNU or SINTEF (where SFI AutoShip was one of the contributors), recommendations on how to strengthen SFIs contributions to innovation are described and published in an open report in 2023.[1]

[1] Innovation resources, NTNU.
NTNU and SINTEF report: Hvordan styrke SFI-enes bidrag til innovasjon? Råd og anbefalinger

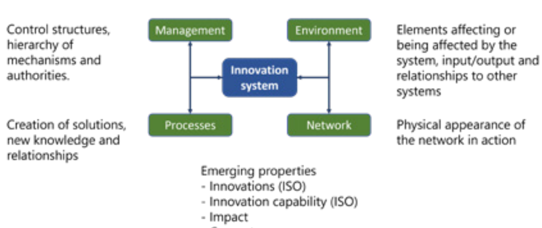
As a foundation for further work, a new system model for collaborative research was developed and published in 2023 (Innovating the Innovation System Thinking: a Systemism Model). Further research on innovation mechanisms in collaborative research will take place in 2024, building on this journal paper.

Outcomes from these competence building activities were presented on the NARMA spring conference and the NEON 2023 conference.

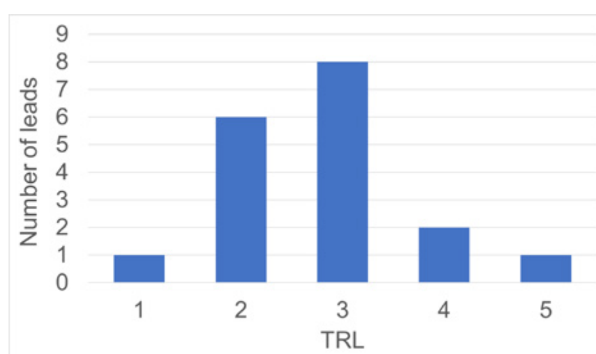
PhD candidate Melih Akdağ pitching results at Ocean week, May 2023. Photo: Raffael Wallner/NTNU

Innovation workshop with SFU Engage in March 2023. Photo: Kjell Olav Skjølsvik/NTNU

The innovation process, as illustrated in the Centre's exploitation plan.



A metamodel of an innovation system such as SFI AutoShip.
Source: Skjølsvik, K.O., Kaloudis, A. Innovating the Innovation System Thinking: a Systemism Model. J Knowl Econ (2023).



TRL status overview of PhD and PD projects in SFI AutoShip, per February 2024.

Conducting field trials with autonomous ships

By Miguel Hinostroza, researcher at the Dept. of Engineering Cybernetics, NTNU

Introduction
In recent years, autonomous ships have been a core research and innovation topic in both industry and academia. Norway is at the forefront of these developments, with a few notable examples being: the Yara Birkeland project by Kongsberg Maritime, the world's first electric autonomous cargo vessel; The milliAmpere ferry concept by NTNU, an autonomous passenger ferry designed for urban transportation, which later evolved into the world's first commercial autonomous passenger ferry in Stockholm, Sweden, by Zeabuz and Torghatten; The upcoming world's first uncrewed freight route at sea in the Trondheimsfjord, by Maritime Robotics.

SFI AutoShip has been developing innovative perception and decision-making systems to ensure the safe navigation of autonomous ships. These systems require testing and validation through field trials before they are ready to be installed on full-scale autonomous ships. Conducting field trials involves a comprehensive and systematic approach to testing and validating the technology in real-world conditions. To perform field trials, several components are relevant: first, a testing platform equipped with modern and accurate sensors, and favourable weather conditions.

Figure 1: Advanced testing platform milliAmpere 2, docked at a channel in Trondheim, Norway.

Sensors and Equipment

Autonomous ships are equipped with modern and complex systems, comprising several maritime sensors and equipment that facilitate safe navigation by avoiding obstacles and enabling communication with shore centers. Thus, the guidance navigation system provides accurate position, orientation, and velocity information, utilizing GPS and an Inertial Measurement Unit (IMU). The control system manages engines, thrusters, rudders, and other components to execute commands. The communication system utilizes satellite or mobile communication to connect with other ships, ports, and control centers on land. The Radar, lidar, and cameras guide the ship through the sea, with these sensors interpreting the surroundings to ensure safe navigation. Figure 2 presents the sensors and equipment onboard NTNU "milliAmpere 1".

Weather conditions for field trials

Autonomous ships are designed to operate in rough weather conditions; however, their performance can be influenced by factors such as wind, waves, or other environmental disturbances. Field trials take into account various scenarios, from calm seas to turbulent waters, to assess how these vessels adapt and respond. Rain, snow, and high winds are among the factors considered, as they can impact sensor accuracy and navigation algorithms. By testing diverse weather conditions, researchers gain insights into the reliability and robustness of autonomous systems. Figure 1 presents milliAmpere 2, an autonomous ferry, an advanced platform for testing that has the capability to conduct trials for perception and decision-making systems.

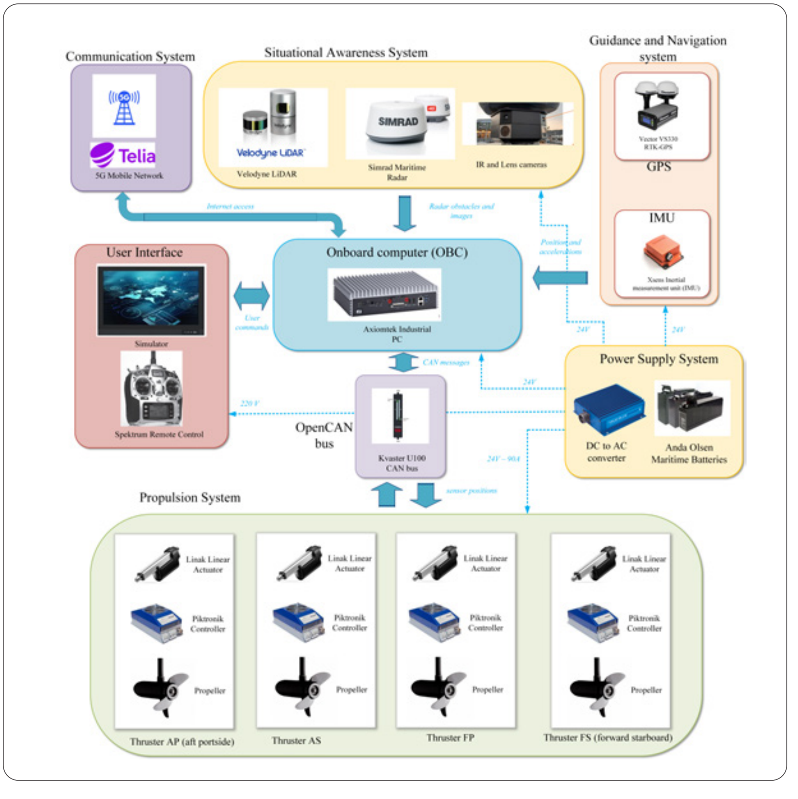


Figure 2: Sensors and equipment onboard of milliAmpere 1 autonomous ferry.

Site visits

WP leader for Use cases Trond Johnsen organized four site visits with PhDs and PDs during 2023. PhD Candidates Simon Lexau, Susanna Dybwad Kristensen and Raffael Wallner visited SFI partner Reach Subsea in Haugesund in February, as part of Use Case 4 Offshore support operations, coordinated by Use case owner Equinor. Reach personnel gave introductions to ongoing offshore support operations and technology, followed by discussions around the use of unmanned surface vessels (USVs). Equinor also participated in the workshop.

While in Haugesund, the Norwegian Maritime Authority (NMA) facilitated a workshop focusing on the risk-assessment of USVs and autonomous ships in general. DNV also contributed to this workshop with their insight from a classification perspective.

A third Use Case 4 site visit coordinated by Equinor with the same researchers was organized shortly afterwards, to SFI partner Fugro in Nootdorp in the Netherlands. PhDs received a guided tour around the Fugro TechCentre and a remote live tour of the Remote Operation Centre in Aberdeen. From this ROC, both ROVs and USVs are remotely operated.

Finally, two Work Package 3 researchers, Taufik Akbar Sitompul and Felix-Marcel Petermann, visited Fugro's Remote Operation Centres (ROCs) in Aberdeen, Scotland in August. They observed the facilities of Fugro's ROCs, which included the ROCs for the unmanned surface vehicle (USV) Orca and the remote-operated vessel (ROV) Blue Essence.

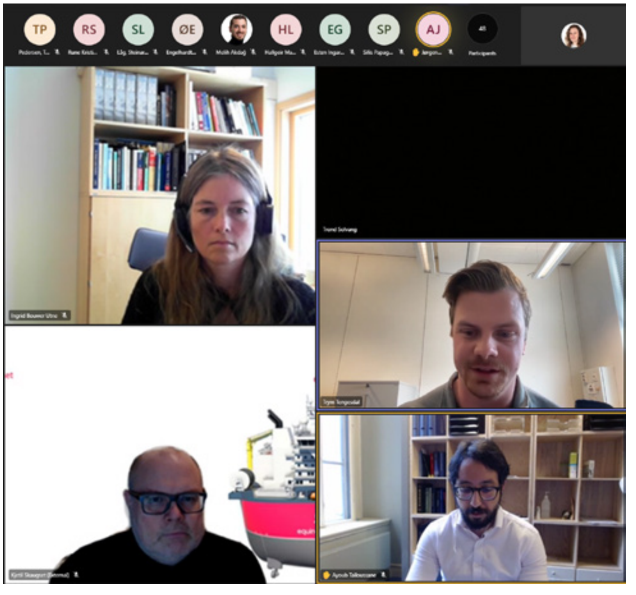
The researchers also interviewed a superintendent and the global product manager of Fugro, who shared their insights into the transition from conventional vessel-based operations to ROC-based operations. The field trip was a valuable learning experience for the researchers, who hope to apply their findings to improve the design and evaluation of autonomous and remote-controlled vessels.

PhD Candidates Simon Lexau, Susanna Dybwad Kristensen and Raffael Wallner in Haugesund, with Reach vessel Havila Subsea in the background.
Photo: Trond Johnsen/SINTEF

Centre researchers with Fugro and Equinor personnel in Nootdorp, the Netherlands. Photo: Trond Johnsen/SINTEF

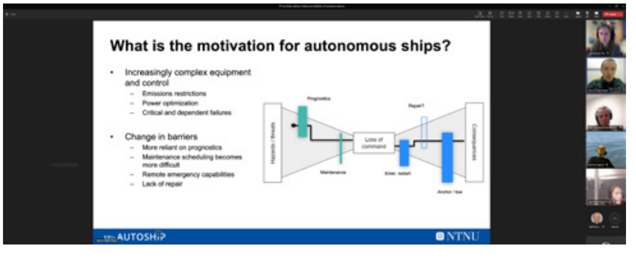
Postdoc Taufik Akbar Sitompul and PhD Candidate Felix-Marcel Petermann, visiting Fugro in Aberdeen, Scotland. Photo: Mark Bruce/Fugro

Site visit at Reach Subsea in Haugesund, sFebruary 2023. Photo: Trond Johnsen/SINTEF



Webinar on COLREGS, 22 March 2023.

Webinar on Remote control rooms, 14 November 2023.



Webinar on Safety and reliability of machinery systems, 11 December 2023.

Webinars

The Centre started arranging regular webinars during 2023 and will continue this going forward. The webinars have been consistently well attended and have been a great way for researchers and industry/public sector partners to collaborate. Recordings are available to the consortium in Teams.

Overview of webinars in 2023:

1. Feasibility study of an unmanned cargo ship (SINTEF)
2. Bridging the gap between COLREGS and algorithms for collision avoidance (NTNU, UiO, DNV)
3. Automated docking for marine surface vessels (NTNU, Kongsberg Maritime, DNV)
4. Condition monitoring (NTNU, DNV)
5. Remote control rooms (NTNU)
6. AEGIS project (NCL, MacGregor, Trondheim Havn, SINTEF)
7. Safety and reliability of machinery systems (NTNU, Torghatten)

Perspectives from our Partners

Fugro

At Fugro, we unlock the secrets of the earth in the form of geo-data, which we apply to develop safer, more sustainable, and more efficient operations, onshore and offshore.

Remote operations are a key component, as they are enabling our business growth, and Autonomy is a fundamental aspect of it.

We have begun the move from conventional operations to uncrewed and remotely controlled assets (USVs & ROVs) to eventually fully autonomous spreads, interoperable, and controlled 24/7 from our Remote Operation Centres around the world.

SFI AutoShip is a highly valuable initiative which will bring mutual benefits. We are currently looking at a wide spread of functionalities ranging from practical operational features to AI based decision making, as well as legal acceptation of computer-generated trajectories. At the same time we have concrete operations experience with a growing fleet of remotely operated vessels, we already collect data and learn every day what is needed to further improve them. SFI AutoShip is for us a platform to learn from world-class researcher and to feed them at the same time with experience, insights and data from the real world.

Human machine interaction, simulations, AI techniques, the impact on legal and permitting aspects for the operation of autonomous vehicles, swarms and vehicle - vehicle interaction, self-enabled autonomy, digital worlds and synthetic environments, all these and more aspects are incredibly important for us, and we see that SFI AutoShip really pushes the limits.

We at Fugro are excited to embark on another year in this journey, and are looking forward to a fruitful cooperation with all the researchers!

The Blue Essence ROV in Rosyth, Scotland. Photo: Fugro

Live Jacob Sydness, VP Head of Sustainable Business and Jarle Fosen, Senior Loss Prevention Executive, Gard.

Gard

How can the SFI help Gard fulfil its goals?
Geopolitical conflicts, sanctions, connectivity, digitalization, autonomy, and decarbonization are transforming the maritime industries, requiring shipowners to adopt new ways of operating and exposing them to new risks and challenges.

Gard already insures remotely controlled unmanned surface vehicles and cargo ships planning to sail autonomously in the future. Our insured owners and clients are embracing autonomous and remote-control technology, and, as an insurer, we need to understand the risks this can bring to help our clients navigate this changing world. As a world leading provider of marine insurance, our role is to support the industry in this technology transition. To do that, we need ensure that we understand the future of the industry we insure.

The work undertaken by the SFI AutoShip research center can help reduce the risk of accidents and incidents, leading to a reduction in the number of insurance claims and payouts. Supporting the SFI AutoShip research centre will assist us in our work towards achieving our goals of preventing losses and in fulfilling our mission for a safe and sustainable shipping industry.

Gard's plans for collaborating in the SFI
Gard plans to continue to be an active industry partner for the SFI AutoShip research center. We will continue to participate in and contribute to the research workshops and other meetings with constructive feedback, and through sharing industry knowledge and claims data. Our active participation in work packages 3, 4, 5, and 6 will continue. These focus on topics such as human factors, sustainability, safety and assurance, maritime law and liability issues, and the use cases defined in the SFI AutoShip.

Through our involvement we aim to increase our knowledge and awareness of technologies and risks related to autonomous ship transportation. The open research results received from SFI AutoShip is actively shared and presented internally in Gard and to shipowner clients of interest.

Gard, as one of the members of the board, will do our best to ensure that the goals, vision, and mission for the SFI AutoShip center is fulfilled. We will contribute to Norwegian organisations taking a leading role in the development of autonomous ships and to ensure safe and sustainable operations.

Pål André Eriksen, Senior Vice President, Kongsberg Maritime.

Kongsberg Maritime

Kongsberg Maritime (KM) is a leading player in the maritime industry, providing cutting-edge technology, equipment, and services for sustainable maritime operations. The Centre for Research-based Innovation (SFI) AutoShip, with its focus on autonomous ships for safe and sustainable operations, aligns perfectly with KM's vision, shaping the maritime future. The collaboration between KM and SFI AutoShip is considered beneficial, and we have clear expectations towards our investment in the SFI .

SFIs work on enabling technologies is expected to contribute to building knowhow and competence required to enable uncrewed operations in the wider market. Particularly, the focus on artificial intelligence and autonomous control (including vessel to shore and remote operation center establishment) is seen beneficial in this context.

Moreover, SFI AutoShip's emphasis on new business models and operational concepts is expected to bring KM knowhow that could be adapted further into the evolving maritime industry and our solutions. From KM point of view, it is essential that the development in general is focused on being cost-effective, focused on operation and solving customer pain points. With the overall aim of adaptation of solutions that is efficient and contribute to reduced operational costs, in this context with a good reflection on the alternative cost and the requirements towards the actors to make this happen.

Furthermore, SFI AutoShip's work on methods and models for monitoring risk and clarifying legal aspects of liability when a captain is not on board can provide KM with valuable insights. This can help KM navigate the complex legal landscape associated with autonomous maritime operations that is still under development, ensuring compliance, and minimizing potential legal risks. We also expect the SFI to have a proactive dialog with relevant governmental authorities, as the Norwegian Maritime Authority (NMA) and leading classification societies within the emerging field.

In conclusion, the collaboration with SFI is evaluated as a positive contribution towards KM's aim of staying at the forefront of the maritime industry, facilitating a transition towards more autonomous, digitalized, and decarbonized operations. Access to cutting-edge research and innovation, is in general an enabler for growth and a requirement to progress, we expect the research in the SFI to be world leading within the prioritized field. However, the actual benefits would depend on various factors, including the successful implementation and integration of the technologies and concepts developed through this collaboration.

Norwegian Maritime Authority

Håvard Gåseidnes, Head of Department, Norwegian Maritime Authority.

Nils Haktor Bua, Head of Section, Norwegian Maritime Authority.

Rune Magne Nilsen, Senior Surveyor, Norwegian Maritime Authority.

As the Norwegian fleet of all types of ships, their ship owners and the rest of the maritime cluster are working towards the climate goals set for 2030 and 2050, it brings up challenges for us as a regulatory and supervisory body. Through more automation and or more use of remote operation of ship and ship systems, the market seeks to make a more efficient shipping, better working conditions and safer operations. To reach these ambitions, not only in the aim of working, but also in a safe and sustainable way, a lot of research is necessary.

Research, as done in SFI Autoship, put lights on theses challenges and aim for solutions, which is helpful information in the work we are doing. The Norwegian Maritime Authority have a substantial interest in the research done on different subjects around autonomous and remote operation of ships. To handle new technology projects and at the end make regulations we are dependent on input on the risks, maturity of technology and possible safe solutions.

Together with the outcome of research from SFI Autoship, NMA have interest and great benefit in joining the discussions throughout the work. Workshops held by the SFI gives us the opportunity to discuss and gather input from many different stakeholders together with the researchers in the center.

The long duration of the SFI makes it possible for the research to follow the development in the real world ship automation projects going on, and in that way be more relevant than other more short term research projects. This also gives the possibility for a stable contact between us and the SFI, and the opportunity to give input and gather feedback on the relevant challenges we see along the way.

NMA will follow and join in to relevant work and workshops, and also be available for giving input to the researchers when necessary during the next years of the SFI, and are happy to be part of the consortium.

Inger Berge Hagen, Project Manager, Torghatten.

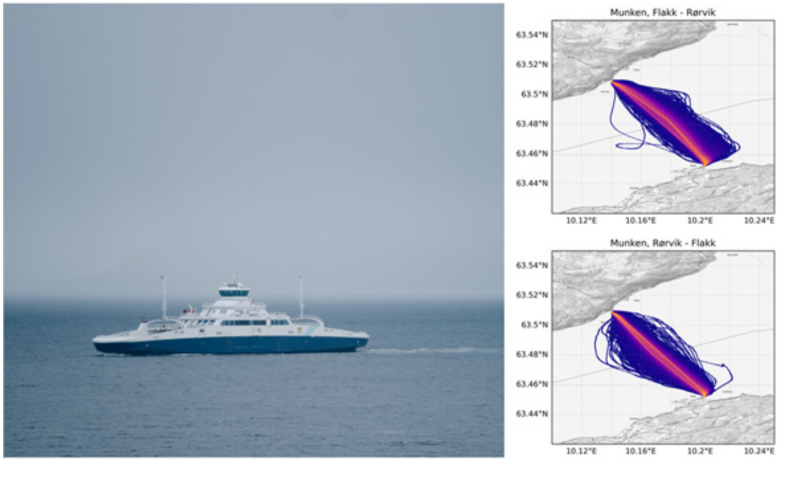
Torghatten

For more than 140 years Torghatten has made it possible for people to live in all the small communities along the long coast of Norway by providing reliable ferry connections. We are now transitioning to more environmentally friendly energy sources and aim to achieve zero emissions by 2040. In parallel with this, we are continually working on optimizing our operations, the main focus areas being safety, fuel efficiency and maintenance. All of which, topics that have been touched upon within our involvement in SFI AutoShip.

At the end of 2023 we finished a project on optimal trajectory selection for fuel efficiency for ferries. We are currently investigating how to best follow up on the results from this and are looking into forming a new project for 2024.

Situational awareness (SA) is a key factor when it comes to assuring safe navigation of our ferries. This is true for all vessels, whether controlled by a captain or running autonomously. An SA system can provide decision support to a human operator or provide input to navigation and collision avoidance systems. In either case, the methods for collecting, fusing and interpreting the different sensor data will determine the reliability of the resulting interpretation. The development of such methods is highly dependent on access to relevant data, and for 2024 one of our goals is to contribute to the creation of such a dataset from one of our ferries at Flakk-Rørvik. The planned data collection campaign will provide the project with data that may highlight needs specific to ferry operations. The campaign will further give Torghatten more insight into the suitability of different sensors and provide information on where they should be positioned onboard the vessel.

Through last year's webinar series we have been kept up to date with the ongoing work in the different work packages. We have also presented on our thoughts concerning the role of prognostics and predictive maintenance in current and future operations. The webinars have boosted the communications between research and industry, and sparked interesting discussions – which we wish to keep engaging in going forward.



MF Munken and historical AIS tracks. Use case for optimal trajectory selection.

International Collaboration

Autonomous ship technology is an area where Norway aspires to stay ahead of the international competition and become established as a world leader. SFI AutoShip aims to contribute to this goal by gathering all central Norwegian actors in the same consortium to address a number of important research challenges associated to autonomous ships. To this end, the consortium continuously keeps good track of key initiatives outside Norway. We have strong ties and exchange information with the following flagship European projects, where some of our partners have significant roles:

- H2020 AutoShip
- AEGIS
- AutoBARGE
- SEAMLESSS
- AUTOFLEX

SFI AutoShip regularly benefits from the international networks of our researchers, who participated in various international conferences and workshops in 2023. SFI personnel have collaborated with researchers within maritime autonomy at the Centre for Collaborative Autonomous Systems at DTU in Denmark. We are also in close contact with key researchers at TU Delft in the Netherlands, including co-publishing and collaboration in EU projects. The Roboats project, a collaboration between MIT and the city of Amsterdam, is directly associated with the SFI's Use case 3, Urban ferries. Collaboration has also been established with researchers at the University of Oklahoma, USA, and the University of Genoa, Italy. We hosted a visiting PhD student from the University of Genoa during the spring of 2023, and she will be returning for a new stay in 2024.

The Centre is fortunate to have an international group of researchers, and 3 of our PhD candidates in 2023 were 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.

We have recently interacted with delegations from Brazil and India, including a presentation of SFI AutoShip at a high-level visit in Chennai, India in November 2023. In both cases, our Brazilian and Indian contacts wish to establish collaboration with our Centre. The Centre has been presented to many important stakeholders in Norway and abroad during 2023. Finally, SFI personnel have participated in international forums and projects, benefiting international institutions and processes.

Scientific Advisory Committee

Our Scientific Advisory Committee headed by Thor I. Fossen, NTNU, was activated in 2023. The committee's member are Paolo Braca from the NATO Science and Technology Organization and Nikolaos Ventikos from the School of Naval Architecture and Marine Engineering, National Technical University of Athens. The committee attended SFI AutoShip days in October and delivered a report, which has been submitted to the Board. According to the report, the committee found the Centre's activities to be of very high quality compared to international standards, and also described the Centre as unique, with respect to the diversity of topics it addresses, as well as the cohesion among these topics. Of recommendations for improvement, they suggested collaborating with meteorology and oceanography experts, and using more seasoned researchers such as postdocs to create a dynamic internal structure with our large number of PhD students.

The Scientific Advisory Committee (SAC) during the SFI Days 2023. From left: SAC member Nikolaos P. Ventikos (National Technical University of Athens), Centre director Anastasios Lekkas (NTNU), SAC leader Thor I. Fossen (NTNU), SAC member Paolo Braca (NATO Science and Technology Organization), and Innovation manager Kjell Olav Skjølsvik (NTNU). Photo: Ingeborg Guldal/NTNU.

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 3 PhDs and 1 researcher to the Centre in 2023.

Name	PhD project	Work package	Supervisor	Host department
Emir Cem Gezer (PhD)	Risk-aware and safeguarding control for autonomous ships	4	Roger Skjetne	Dept. of Marine Technology
Miguel Hinostroza (researcher)	Motion control and collision avoidance for autonomous surface vessels, validated via full-scale implementations	1	Edmund Brekke	Dept. of Engineering Cybernetics
Peter Morris (PhD)	Data Fusion in Maritime IoT	2	Pierluigi Salvo Rossi	Dept. of Electronic Systems
Sreekant Sreedharan (PhD)	Safety Assessment and Verification of Collision and Grounding Avoidance Algorithms - Simulation Workbench for COLREG Compliance Testing	4	Børge Rokseth	Dept. of Engineering Cybernetics

The first PhD/PD gathering after all new researchers in 2023 had arrived - Innovation workshop in December 2023. Anders Aune from NTNU Technology Transfer presenting. Photo: Ingeborg Guldal/NTNU.

Researchers in WP1 and WP2 discussing with partner representatives during the autumn researcher workshop in September 2023. Photo: Ingeborg Guldal/NTNU.

Miguel Hinostroza, Researcher working on field trials in Work Package 1, Dept. of Engineering Cybernetics, NTNU.

PhDs and Postdocs

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

Luka Grgičević
Decision Support Systems for Autonomous Vessels
Supervisors: Erlend Magnus Lervik Coates, Ottar L. Osen and Robin T. Bye (IIR, NTNU), Thor I. Fossen (ITK, NTNU)

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

Lukas Herrmann
Real-time ship-shore radar
Supervisors: Egil Eide (IES, NTNU), Edmund Brekke (ITK, NTNU), Andreas Brandsæter (IIR, NTNU)

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

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

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

Simon Lexau
Autonomous Docking for Marine Surface Vessels
Supervisors: Anastasios Lekkas and Morten Breivik (ITK, NTNU)

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

Andreas Nygard Madsen
AI decision transparency in autonomous shipping
Supervisors: Magne Aarset (IHB, NTNU), Ole Andreas Alsos (Design, NTNU), Tae-Eun Kim (UiT), Andreas Brandsæter (IIR, NTNU)

Emil Martens
Multi Sensor Detection for Autonomous Surface Vessels
Supervisors: Annette Stahl and Edmund Førland Brekke (ITK, NTNU), Rudolf Mester (IDI, NTNU)

Trym Tengesdal
Machine learning methods applied to parameter identification and automatic adjustment of ship motion planning algorithms
Supervisor: Tor Arne Johansen (ITK, NTNU)

Daniel Menges
Situational Awareness and Control of Autonomous Surface Vessels Using Digital Twins
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)

Emir Cem Gezer
Risk-aware and safeguarding control for autonomous ships
Supervisors: Roger Skjetne and Ingrid B. Utne (IMT, NTNU), Morten Breivik (ITK, NTNU)

Taufik Akbar Sitompul
Human-machine interface for remote crane operation
Supervisor: Ole Andreas Alsos (Dept. of Design, NTNU)

Peter Morris
Data Fusion in Maritime IoT
Supervisor: Pierluigi Salvo Rossi

Ayoub Tailoussane
COLREGS-compliance in the era of Autonomous Vessels – Legal challenges and future perspectives
Supervisors: Trond Solvang (NIFS, UiO), Dag Wiese Schartum (IFP, UiO)

Sreekant Sreedharan
Safety assessment and verification of collision avoidance algorithms for autonomous ships
Supervisor: Børge Rokseth (ITK, NTNU)

SFI AutoShip in the media

Visit from the Minister of Foreign Affairs

Minister of Foreign Affairs Anniken Huitfeldt visited NTNU Nyhavna and the Shore Control Lab in January 2023. Image from NRK news coverage, showing the Minister and NTNU Rector Anne Borg with SFI AutoShip PhD Candidate Felix-Marcel Petermann.


Skipsrevyen KONTAKT OSS JOBB BÅTOMTALER SHIP OF THE YEAR AIS LOGG INN

Maritim Forskning:

Er førerløse skip løsningen på mannskapsmangel og utrygge arbeidsforhold til sjøs?

Mannskapsmangel og ulykkesrisiko til sjøs har vært fremtredende tema i maritim sektor den siste tiden. Foto: NTNU

I 2022 ble over 700 fergeavganger i Norge innstilt på grunn av mannskapsmangel. Det er kanskje en promille av den totale fergetrafikken langs riksveisambandet, men koster likevel samfunnet flere millioner kroner årlig.

Ole Andreas Alsos
PRODEKAN FOR INNOVASJON VED INSTITUTT FOR DESIGN, NTNU

Birgit Thorsen
OCEAN AUTONOMY CLUSTER OG FREMTIDENS INDUSTRI

PUBLISERT Onsdag 15. november 2023 - 12:09 SIST OPPDATERT Onsdag 15. november 2023 - 12:10

Høy ulykkesrisiko og stress er blant årsakene til at mange velger seg bort fra et arbeidsliv til sjøs. Det er på tide å snakke høyt om hvordan ny teknologi kan spille på lag for en tryggere og mer effektiv arbeidshverdag til sjøs.

Skipsrevyen, «Er førerløse skip løsningen på mannskapsmangel og utrygge arbeidsforhold til sjøs?» by Ole Andreas Alsos and Birgit Thorsen, 15.11.2023.


Maritim Forskning

Selvkjørende ferjer er ikke lik «ingen mennesker»

Hva er egentlig et autonomt skip? Faktisk er det mer sannsynlig at bemannede skip med automatiserte prosesser og beslutningsstøtte vil bli mest vanlig, skriver havromsstipendiat Andreas Madsen fra NTNU.

Andreas Madsen. Stipendiat, Institutt for havromsoperasjoner og byggteknikk, NTNU

Om forfatteren: Andreas Nygard Madsen er PhD kandidat ved NTNU i Ålesund og forsker på hvordan man kan sikre god samhandling mellom navigatører og kunstig intelligens (AI).

Andreas Madsen. Stipendiat, Institutt for havromsoperasjoner og byggteknikk, NTNU. Foto: NTNU

Skipsrevyen, «Selvkjørende ferjer er ikke lik «ingen mennesker», by Andreas Nygard Madsen, May 2023.

Comments on the future and potential of autonomous ships

SFI researchers Tor Arne Johansen, Ole Andres Alsos and Andreas Nygard Madsen each contributed with opinion pieces in journals Nature (below) and Skipsrevyen (previous page), during 2023.

COMMENT | 27 February 2023

Autonomous ships are on the horizon: here's what we need to know

Ships and ports are ripe for operation without humans – but only if the maritime industry can work through the practical, legal and economic implications first.

By Rudy R. Negenborn, Floris Goerlandt, Tor A. Johansen, Peter Slaets, Osiris A. Valdez Banda, Thierry Vanelslander & Nikolaos P. Ventikos

By 2024, the Norwegian container ship Yara Birkeland is expected to carry fertilizer autonomously from plant to port with zero emissions. Credit: Torstein Bøe/NTB/AFP via Getty

Nature, "Autonomous ships are on the horizon: here's what we need to know" by Rudy R. Negenborn, Floris Goerlandt, Tor A. Johansen, Peter Slaets, Osiris A. Valdez Banda, Thierry Vanelslander & Nikolaos P. Ventikos, 27.02.2023.

Events

SFI AutoShip Days

We welcomed over 90 participants from our research, industry, and public sector partners to the annual SFI AutoShip Days on 16-17 October. Several consortium partners contributed to a strong programme, with many interesting presentations and discussions, including:

- Twelve innovation leads, presented by our PhDs and postdoctoral researchers
- Torghatten: Experiences from the world's first autonomous passenger ferry operation in Stockholm
- Kongsberg Maritime: Results from the Autoship H2020 project
- DNV: Testing collision and grounding avoidance systems
- NTNU, IFE and Fugro: Experiences within human factors and remote operations
- NMA and NTNU: Results of large-scale surveys including seafarers' views on autonomy at sea
- Maritime Robotics: an overview of their activities, including the upcoming first uncrewed freight route at sea
- NTNU Technology Transfer: tools for creating value from research, a main goal for our Centre
- SINTEF: an overview of automated mooring systems
- A presentation and posters by international guests from the MSCA ETN AUTOBarge project

Jan Egil Wagnild from Torghatten presenting. Photo: Ingeborg Guldal/NTNU

Ocean Week

SFI AutoShip and Ocean Autonomy Cluster (OAC) co-organized a joint session on Autonomous ships during NTNU's Ocean Week on 2 May, coordinated by our Innovation Manager Kjell Olav Skjølsvik and OAC's Frode Halvorsen. The session was well-attended by approx. 70-80 participants. In addition to introductions to SFI AutoShip and OAC projects, presentations focused on research infrastructure for autonomous ships (NTNU and SINTEF), efforts to increase autonomy in marine operations (Equinor), the short sea shipping use case in the H2020 Autoship project (Kongsberg Maritime), the framework around maritime autonomy (DNV), and preparations for the world's first commercial autonomous ferry operation in Stockholm (Torghatten together with Zeabuz). This was the first event in which four of our researchers held innovation pitches to a larger audience based on their innovation leads - these pitches were further developed before the SFI Days in which most of the Centre researchers presented.

PhD Candidate Susanna Dybwad Kristensen presenting her Innovation pitch. Photo: Raffael Wallner/NTNU

Are Jørgensen from DNV presenting. Photo: Ingeborg Guldal/NTNU

SFI AutoShip Researcher Workshops

The Spring researcher workshop was held in March, and included participation from industry partners DNV, Gard and Maritime Robotics in addition to research partners. The event focused on the involvement of each PhD/postdoc with industry partners and improving cross-work package coordination.

Along with research partners there was increased industry participation in the Autumn researcher workshop in September, including representatives from DNV, Kongsberg Maritime, Fugro and Torghatten. The plenary session offered examples on submission of DOFIs and researcher mobility.

In the parallel sessions according to work packages the annual work plan for 2024 was discussed, and industry contact persons were assigned or planned for each PhD/PD.

Autumn researcher workshop in September. Photo: Ingeborg Guldal/NTNU

Spring researcher workshop in March. Photo: Anastasios Lekkas/NTNU

Publications and Presentations in 2023

TYPE	NAME/DESCRIPTION	NAME OF JOURNAL/ CONFERENCE/BOOK	AUTHOR(S)
Journal articles	Analyzing the Feasibility of an Unmanned Cargo Ship for Different Operational Phases	TransNav, International Journal on Marine Navigation and Safety of Sea Transportation	Pauline Røstum Bellingmo, Egil Wille, Håvard Nordahl, Odd Erik Mørkrid and Even Ambros Holte
	Rederens erstatningsansvar ved sammenstøt mellom skip	MarIus, periodical published by the Maritime Law Foundation	Markus Engøy Duna
	Risk-based path planning for preventing collisions and groundings of maritime autonomous surface ships	Ocean Engineering	Renan Guedes Maidana, Susanna Dybwad Kristensen, Ingrid Bouwer Utne and Asgeir Johan Sørensen
	Predictive digital twins for autonomous surface vessels	Ocean Engineering	Agus Ismail Hasan, Augie Widyotriatmo, Eirik Strøm Fagerhaug and Ottar Laurits Osen
	Maritime Tracking with Georeferenced Multi-Camera Fusion	IEEE Access	Øystein Kaarstad Helgesen, Annette Stahl and Edmund Førland Brekke
	Experimental validation of camera-based maritime collision avoidance for autonomous urban passenger ferries	MIC Journal: Modeling, Identification and Control	Øystein Kaarstad Helgesen, Emil Hjelseth Thyri, Edmund Førland Brekke, Annette Stahl and Morten Breivik
	Variations of Joint Integrated Data Association With Radar and Target-Provided Measurements	Journal of Advances in Information Fusion	Audun Gullikstad Hem and Edmund Førland Brekke
	Histogram-probabilistic multi-hypothesis tracking with a Poisson mixture measurement process	Proceedings of SPIE, the International Society for Optical Engineering	Lukas Herrmann, Edmund Førland Brekke and Egil Sverre Eide
	The rise of automated mooring systems	Hansa - International Maritime Journal	Ulrik Jørgensen, Pauline Røstum Bellingmo and Odd Erik Mørkrid
	Automated Docking for Marine Surface Vessels - A Survey	IEEE Access	Simon Julian Nagelsaker Lexau, Morten Breivik, Anastasios Lekkas
	Four Degree-of-Freedom Hydrodynamic Maneuvering Model of a Small Azipod-Actuated Ship With Application to Onboard Decision Support Systems	IEEE Access	Mathias Huuse Marley, Roger Skjetne, Mateusz Gil and Przemyslaw Krata
	An environmental disturbance observer framework for autonomous surface vessels	Ocean Engineering	Daniel Menges and Adil Rasheed

TYPE	NAME/DESCRIPTION	NAME OF JOURNAL/ CONFERENCE/BOOK	AUTHOR(S)
	A gap analysis for automated cargo handling operations with geared vessels frequenting small sized ports	Maritime Transport Research	Mariann Merz,; Esten Ingar Grøtli, Odd Erik Mørkrid, Espen Johansen Tangstad, Synne Fossøy and Håvard Nordahl
	Innovating the Innovation System Thinking: a Systemism Model	Journal of the Knowledge Economy	Kjell Olav Skjølsvik and Aristidis Kaloudis
Conference papers/ workshop presentations	Collaborative Collision and Grounding Avoidance Methods for Autonomous Ships	Brown Bag Seminar	Melih Akdağ
	Conference presentation of trial operation.	ICMASS	Ole Andreas Alsos
	MilliAmpere2 trial operation	LOAS event	Ole Andreas Alsos
	Presentation about trial operation of milliAmpere2	Autonomous Ship Expo Conference	Ole Andreas Alsos
	Hellinger Metrics for Validating High Fidelity Simulators Using Target Tracking	Lecture Notes in Computer Science (LNCS)	Kjetil Vasstein, Øystein Kaarstad Helgesen and Edmund Førland Brekke
	Comparing Multiple Extended Object Tracking with Point Based Multi Object Tracking for LiDAR in a Maritime Context	Journal of Physics: Conference Series (JPCS)	Martin Lukas Baerveldt, Audun Gullikstad Hem and Edmund Førland Brekke
	Automated Mooring Systems	22nd Conference on Computer Applications and Information Technology in the Maritime Industries COMPIT'23	Ulrik Jørgensen, Pauline Røstum Bellingmo and Odd Erik Mørkrid.
	Multiscan Shape Estimation for Extended Object Tracking	IEEE Xplore Digital Library	Michael Ernesto Lopez, Edmund Førland Brekke, Rudolf Mester and Annette Stahl
	Analyzing the Feasibility of an Unmanned Cargo Ship for Different Operational Phases	15th International Conference on Marine Navigation and Safety of Sea Transportation	Pauline Røstum Bellingmo, Egil Wille, Håvard Nordahl, Odd Erik Mørkrid and Even Ambros Holte
	Histogram-probabilistic multi-hypothesis tracking with a Poisson mixture measurement process	SPIE Security + Defence	Lukas Herrmann, Edmund Førland Brekke and Egil Sverre Eide
	SFI AutoShip webinar on AEGIS project	SFI AutoShip webinar	Kenneth Johanson, Janne Suominen, Terje R. Meisler and Odd Erik Mørkrid

TYPE	NAME/DESCRIPTION	NAME OF JOURNAL/ CONFERENCE/BOOK	AUTHOR(S)
	Automated Mooring Systems	22nd Conference on Computer Applications and Information Technology in the Maritime Industries COMPIT'23	Jørgensen, Ulrik; Bellingmo, Pauline Røstum and Odd Erik Mørkrid
	SFI AutoShip webinar on automated docking for marine surface vessels	SFI AutoShip webinar	Simon Julian Nagelsaker Lexau, Kaj-Robin Weslien, Roger Lauritsen, and Anastasios Lekkas
	Multiscan Shape Estimation for Extended Object Tracking	Fusion 2023	Michael Ernesto Lopez, Edmund Førland Brekke, Rudolf Mester and Annette Stahl
	SFI AutoShip Webinar on Condition Monitoring	SFI AutoShip webinar	Daniel Menges, Joar Håland and Edmund Førland Brekke
	Digital Twin for Autonomous Surface Vessels to Generate Situational Awareness	OMAE 2023 42nd International Conference on Ocean, Offshore & Arctic Engineering	Daniel Menges and Adil Rasheed
	Innovation projects overview	Ocean Week	Odd Erik Mørkrid
	SFI Autoship webinar on Feasibility study of an unmanned cargo ship	SFI AutoShip webinar	Odd Erik Mørkrid and Pauline Røstum Bellingmo
	Interaction Between Humans and Autonomous Systems: Human Facing Explanatory Interface for an Urban Autonomous Passenger Ferry	IHSI Conference 2023	Felix-Marcel Petermann
	Digital Twinning of Autonomous Systems	International Conference on Computational Science and AI in Industry	Adil Rasheed
	Analyzing Online Videos to Create a List of User Interface Elements: A Case for OpenCrane Design System.	The 19th IFIP TC.13 International Conference on Human-Computer Interaction (INTERACT 2023)	Taufik Akbar Sitompul
	Designing User Interface Elements for Remotely Operated Rubber-tired Gantry Cranes	The 2023 IEEE International Conference on Systems, Man, and Cybernetics (SMC)	Taufik Akbar Sitompul
	Designing User Interface Elements for Remotely Operated Ship-to-shore Cranes	The 36th International BCS Human-Computer Interaction Conference (BCS HCI 2023)	Taufik Akbar Sitompul
	Evaluating Graphical User Interfaces for Handling Latency in Remote Crane Operation	The 36th International BCS Human-Computer Interaction Conference (BCS HCI 2023)	Taufik Akbar Sitompul

TYPE	NAME/DESCRIPTION	NAME OF JOURNAL/ CONFERENCE/BOOK	AUTHOR(S)
	OpenCrane Design System	Ocean Week 2023	Taufik Akbar Sitompul
	OpenCrane Design System	SFI AutoShip Days 2023	Taufik Akbar Sitompul
	SFI AutoShip webinar: Remote control rooms	SFI AutoShip webinar	Taufik Akbar Sitompul, Felix-Marcel Petermann and Ole Andreas Alsos
	Kommersialisering og IPR - Forutsigbare modeller for utnyttelse av resultater	NARMAs vårkonferanse 2023	Kjell Olav Skjølsvik
	SFI Autoship webinar on bridging the gap between COLREGS and algorithms for collision avoidance	SFI Autoship webinar	Ayoub Tailoussane, Trym Tengesdal, Øystein Engelhardtsen, Tom Arne Pedersen and Ingrid Bouwer Utne
	Modular Collision Avoidance Using Predictive Safety Filters	OMAE 2023 42nd International Conference on Ocean, Offshore & Arctic Engineering	Aksel Vaaler, Haakon Rennesvik Robinson, Trym Tengesdal and Adil Rasheed
	Identifying Test Scenarios for Simulated Safety Demonstration using STPA and CAST	33rd European Safety and Reliability Conference	Raffael Wallner, Bjørn Axel Gran, Tom Arne Pedersen, Tor Arne Johansen and Mary Ann Lundteigen
Reports	Feasibility Study for an Unmanned Deep Sea Bulk Ship and Short Sea Container Ship	SFI AutoShip/ SINTEF report	Pauline Røstum Bellingmo, Odd Erik Mørkrid and Egil Wille
	Hvordan styrke SFI-enes bidrag til innovasjon?	NTNU and SINTEF report	Partow Pakdel Henriksen, Ragnhild Nisja, Kristine Vedal Størkersen, Aud Nina Wærnes, Håvard Sletta, Kaja Kristine Haug, Svein-Erik Måsøy, Magnus Langseth, Ottar Henriksen and Kjell Olav Skjølsvik
	Feasibility study for unmanned ferry service for Levanger – Ytterøy: Technical requirements, Retrofit opportunities and Safety Considerations	SINTEF report	Mariann Merz, Esten Ingar Grøtli and Odd Erik Mørkrid
Other presentations and events	Presentation of NTNU Shore Control Lab	Mexican Ambassador visit to SCL	Ole Andreas Alsos and Felix-Marcel Petermann
	Presentation of NTNU Shore Control Lab	Aalborg University and AHO	Ole Andreas Alsos
	Presentation of NTNU Shore Control Lab	Visit from ABB	Ole Andreas Alsos

TYPE	NAME/DESCRIPTION	NAME OF JOURNAL/ CONFERENCE/BOOK	AUTHOR(S)
	Presentation of NTNU Shore Control Lab	After Sea, Ocean Autonomy Cluster	Ole Andreas Alsos
	Presentation of NTNU Shore Control Lab and milliAmpere2	EU commission visit, Dimitri Lorenzani	Ole Andreas Alsos
	Presentation of NTNU Shore Control Lab and milliAmpere2	Delegation from Faroe Islands visit to NTNU	Ole Andreas Alsos
	Presentation of NTNU Shore Control Lab and milliAmpere2	Visit from Turku University	Ole Andreas Alsos
	Presentation of NTNU Shore Control Lab and Lashfire	Minister of Foreign Affairs visit to NTNU	Ole Andreas Alsos and Felix-Marcel Petermann
	Presentation of NTNU Shore Control Lab and milliAmpere2	Ocean Week After Sea	Ole Andreas Alsos
	Presentation of NTNU Shore Control Lab	Visit from Fugro	Ole Andreas Alsos
	Presentation of NTNU Shore Control Lab	Visit from Indian Institute of Technology Madras	Ole Andreas Alsos
	Presentation of NTNU Shore Control Lab	Visit from Kongberg Defence and Aerospace	Ole Andreas Alsos
	Presentation of NTNU Shore Control Lab	Visit from Norwegian Maritime Authority	Ole Andreas Alsos
	Presentation of NTNU Shore Control Lab	Opening of NTNU Nyhavna	Ole Andreas Alsos
	Presentation of NTNU Shore Control Lab	Politecnico Milano visit	Ole Andreas Alsos
	Presentation of NTNU Shore Control Lab	SFI AutoShip Days	Ole Andreas Alsos
	Presentation of NTNU Shore Control Lab	Tokyo University of Marine Science and Technology	Ole Andreas Alsos
	Presentation of NTNU Shore Control Lab	Visit from University of Strathclyde, Glasgow	Ole Andreas Alsos
	Presentation of NTNU Shore Control Lab	Visit from Virginia Tech and SINTEF	Ole Andreas Alsos
	Presentation of NTNU Shore Control Lab	NFAS årsmøte	Ole Andreas Alsos

TYPE	NAME/DESCRIPTION	NAME OF JOURNAL/ CONFERENCE/BOOK	AUTHOR(S)
	Presentation of autonomous ferries	Mobilitetslab stor-Trondheim	Ole Andreas Alsos
	World's best research infrastructure for autonomous ships	Ocean Week	Ole Andreas Alsos
	Presentaion and Demonstration of the NTNU Shore Control Lab and LASHFIRE	Visit of Minister of Foreign Affairs Norway	Ole Andreas Alsos and Felix-Marcel Petermann
	Presentation of the Shore Control Lab (SCL) and LASHFIRE	Roboat Amsterdam and MIT visits NTNU SCL	Ole Andreas Alsos and Felix-Marcel Petermann
	Presentation of the Shore Control Lab (SCL) and LASHFIRE	Official Opening of new Nyhavna Research Infrastructure	Ole Andreas Alsos, Felix-Marcel Petermann and Leander Spyridon Pantelatos
	Presentation of the Shore Control Lab (SCL) and LASHFIRE	Seminar and visit with Turku University	Ole Andreas Alsos, Taufik Akbar Sitompul and Felix-Marcel Petermann
	Presentation of the Shore Control Lab (SCL) and LASHFIRE	Seminar: Designing for Landbased Control of Autonomous Ship	Ole Andreas Alsos, Erik Aleksander Veitch, Felix-Marcel Petermann, Taufik Akbar Sitompul, Stig Thomas Porathe and Alf Ove Braseth.
	An overview of SFI AutoShip	Meeting with Hidrovias do Brasil and Kongsberg Discovery	Anastasios Lekkas
	An overview of SFI Autoship	Guest visit at Technical University of Denmark (DTU)	Anastasios Lekkas
	An overview of SFI Autoship	Meeting with Indian Institute of Technology – Madras	Anastasios Lekkas
	Presentation of NTNU Shore Control Lab (SCL)	Besøket av digitalisering- og forvaltningsminister Karianne Tung	Felix-Marcel Petermann, Ole Andreas Alsos and Taufik Akbar Sitompul
	How can systems thinking help organizations' innovation capacity and navigate successfully in VUCA landscape in BANI times?	NEON dagene 2023	Kjell Olav Skjølsvik and Aristidis Kaloudis
	Autonomy needs Eyes - Vision-based Scene Perception and Interpretation for Autonomous Robots	AMOS Day, The Celebration Closing Event of the Center of Excellence NTNU AMOS	Annette Stahl

Master Students 2023

MASTER THESES WITH SFI AUTOSHIP TOPICS COMPLETED IN 2023

NAME	SEX	THESIS TITLE	SUPERVISORS
Simen Stensrød Allum	M	Camera-Based Perception System for Autonomous Drones in Search-and-Rescue Missions at Sea	Anastasios Lekkas
Daniel Bjerkehagen	M	Automatic Calibration of Ship-mounted Cameras' Extrinsic Parameters	Edmund Brekke
Jon Magnus Lauvrak; Erik Daniel Haukås Moe	M, M	Direct Methods for Detecting and Tracking Objects from Visual Images from Moving Cameras in a Marine Environment	Edmund Brekke
Christopher Strøm	M	Towards robust and flexible point-object multi-target tracking using transformer neural networks	Edmund Brekke
Stian Andre Elvenes	M	Development of C/S Jonny with optimal constrained thrust allocation	Roger Skjetne, Emir Cem Gezer
Jenny Aune Forbord	F	Bayesian range estimate from two- directional phase measurements	Kimmo Kansanen, Carsten Wulff
Helene Engebakken Haugen	F	Validation and development of intention model for collision avoidance at sea	Tor Arne Johansen
Jan-Erik Hygen	M	Deterministic Response Prediction of Wave-induced Vessel Motions	Roger Skjetne, Mathias Marley
Jakob Horn Jernsletten	M	Autonomous search and rescue using an autonomous surface vessel	Anastasios Lekkas, Tom Arne Pedersen
Gunnar Skålheim	M	Path planning and path following for Surface Operating Vessels (SOVs) in offshore wind farms	Tor Arne Johansen
Ege Kandemir	M	Sparse Identification of Nonlinear Dynamics in Digital Twins for an Unmanned Surface Vessel	Erlend M. Coates, Agus Ismail Hasan
Trym Overrein Lunde	M	Path Planning and Path Following in Offshore Wind Applications	Tor Arne Johansen
Peder Lycke	M	Situation-dependant tuning of a collision avoidance algorithm for surface vessels with grounding hazard consideration	Tor Arne Johansen
Ludvig Vik Løite	M	Simulation-Based, Risk-Influenced Path Planning Framework for Marine Surface Vessels	Børge Rokseth
Magnus Løvold Kvebæk	M	Development of C/S Jonny incorporating an adaptive autopilot with a velocity guidance safety layer	Roger Skjetne, Emir Cem Gezer
Emil Ludvig Martens	M	Paving the Way for Enhanced Situational Awareness in the Maritime Domain: Designing and Assembling a Sensor Rig for Multi-Sensor Data Set Acquisition	Annette Stahl, Edmund Brekke, Rudolf Mester
Eirik Midtun	M	Performance analysis of dynamic positioning observer algorithms: Application to the cybership models in MC-Lab	Roger Skjetne, Emir Cem Gezer
Harald Mo; Marie Fejerskov Kongshaug	M, F	Real-time compensation of residual loads in dynamic positioning control systems	Roger Skjetne, Mathias Marley, Emir Cem Gezer
Kristian Nilsen	M	Planning, Scheduling and Control for Autonomous Passenger Ferry Operations in Urban Environments	Anastasios Lekkas
Henrik Rohde Nordhus	M	COLREGs-aware automatic docking for autonomous surface vessels	Anastasios Lekkas, Morten Breivik, Thomas Johansen

NAME	SEX	THESIS TITLE	SUPERVISORS
Børge Pahlm	M	Trade-off between accuracy and time consumption in optimization algorithms for thrust allocation	Tor Arne Johansen
James Premraj	M	Development of a Digital Twin for the Marine Cybernetics Lab: 3D visualization and simulation, online monitoring, and remote control	Roger Skjetne
Aksel Vaaler; Svein Jostein Husa	M, M	Safe Reinforcement Learning in Marine Navigation and Control: Using a Predictive Safety Filter for Safety Verification on Autonomous Surface Vessels	Adil Rasheed
Luis Fernando Sanchez Martin	M	Online Digital Twin and a Decision Support for Safe Maneuvering of R/V Gunnerus	Roger Skjetne, Mathias Marley
Aurora Opheim Sauar	F	Explainable Artificial Intelligence for the docking of a marine vessel using SHAP and LIME	Anastasios Lekkas
Øystein Solbø	M	Towards mission planning for search and rescue at sea	Anastasios Lekkas
Ane Joramo Stokke	F	Autonomous ship testing environment (ASTE): A simulation-based framework for testing of autonomous ships	Børge Rokseth
Johan Suárez	M	Improving Accuracy of MCPD Distance Measurements	Kimmo Kansanen, Carsten Wulff

Annual Accounts for 2023

All figures in 1000 NOK.

FUNDING	AMOUNT
The Research Council	12 751
The Host Institution (NTNU)	12 877
Research Partners*	1 133
Enterprise partners**	9 811
Public partners***	277
Total	**36 849**

COSTS	AMOUNT
The Host Institution (NTNU)	24 103
Research Partners*	6 590
Enterprise partners**	5 879
Public partners***	277
Total	**36 849**

*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
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 and WP 4 leader
Trond Johnsen	Centre co-director and WP 6 leader
Kjell Olav Skjølsvik	Innovation manager
Ingeborg Guldal	Administrative coordinator
Steve Harila Løkkeberg	Economist

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
Annette Stahl	Dept. of Engineering Cybernetics	Robotic vision
Børge Rokseth	Dept. of Engineering Cybernetics	Safety assurance of autonomous systems
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
Erlend Magnus Lervik Coates	Dept. of ICT and Natural Sciences	GNC, propulsion and autonomous systems
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
Lars Ivar Hatledal	Dept. of ICT and Natural Sciences	Software engineering / co-simulation
Magne Aarset	Dept. of Ocean Operations and Civil Engineering	Risk Mnagement/Artificial Intelligent
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 intelligens
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	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
Eirik Flemsæter Falck	SINTEF Digital	Detection, tracking, crane control
Esten Ingar Grøtli	SINTEF Digital	Sensor fusion, estimation, path planning
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
Martin Brandt	SINTEF Digital	Sensor fusion and motion
Espen Tangstad	SINTEF Ocean	Autonomous control system
Even Ambros Holte	SINTEF Ocean	Maritime logistics and autonomous shipping
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

KEY RESEARCHERS	IFE	MAIN RESEARCH AREA
Alf Ove Braseth	Principal Scientist	Control room and interaction design
Bjørn Axel Gran	Research director	Risk, safety and security
Linda Sofie Lunde-Hanssen	Senior Scientist	Control room and interaction design
Prosper A. Kwei-Narh	Senior Research Scientist	Human-Centred Digitalization
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	01.08.2022-31.12.2023	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 Akdağ	M	Turkish	20.05.2021-19.05.2024	Collaborative collision avoidance for autonomous ships
Susanna Dybwad Kristensen	F	Norwegian	16.08.2021-15.08.2025	Online risk modeling of autonomous ships
Henrik Dobbe Flemmen	M	Norwegian	01.11.2021-31.10.2024	Non-GNSS localization for USVs (aka SLAM)
Emil Martens	M	Norwegian	11.08.2021-11.08.2026	Multi-sensor objetc detection and classification
Felix Marcel Peterman	M	German	01.08.2021-30.11.2025	Interaction Design
Andreas Nygard Madsen	M	Norwegian	01.09.2021-31.07.2024	AI decision transparency in autonomous maritime operations
Eirik Fagerhaug	M	Norwegian	01.08.2021-01.08.2025	Explainable AI for autonomous ships
Spencer Dugan	M	American	01.09.2021-30.04.2025	Risk acceptance and operational constraints in risk modeling of autonomous operations.
Ayoub Tailoussane	M	Moroccan	02.11.2021- 02.11.2024	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	15.06.2022-15.07.2025	Real-time ship-shore radar
Daniel Menges	M	German	17.01.2022-30.01.2025	SITAW: The ship and its surroundings/collision avoidance
Luka Grgčević	M	Croatian	28.01.2022-28.01.2025	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?

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