ANNUAL REPORT
2021

SFI·AUTOSHIP

Autonomous ships for safe and sustainable operations

FUNDING AGENCY

Forskningsrådet

RESEARCH PARTNERS

SINTEF   IFE   UiO:

INDUSTRY PARTNERS

MARITIME ROBOTICS   idletechs   equinor   DNV   G2 OCEAN

GRIEG STAR   EMBRON   massterly
a Kongsberg Wilhelmsen joint venture   MACGREGOR

Telia   KONGSBERG   NCL North Sea Container Line   TORGHATTEN   gard

PUBLIC AND GOVERNMENTAL PARTNERS

Sjøfartsdirektoratet
Norwegian Maritime Authority   Trondheim Havn   TRONDHEIM KOMMUNE   KYSTVERKET

HOST

NTNU | Faculty of Information Technology
and Electrical Engineering
Department of Engineering Cybernetics

⊙ 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 senters (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.

Centre Director

Since SFI AutoShip formally opened December 1st 2020, we have put a lot of effort into defining our profile, creating collaboration structures, conducting workshops and seminars on relevant topics as well as focusing on promoting the Centre. A definite highlight this year was having the SFI days in September when we finally could meet in real life!

One of the strengths of SFI AutoShip is the trans-disciplinary structure and large number of partners from the industry, public sector and research institutions. With such diversity in our project portfolio there is great potential for innovation in several areas within the development of autonomous ships. We therefore have innovation high up on the agenda and in 2021 an Innovation and Commercialization Advisory Committee was established. One of our work packages is solely focused on use-cases and these have now been defined in close collaboration with the industry partners.

2021 was a year when we recruited 10 PhDs and one post doc. Onboarding during a pandemic is challenging, but through online, joint colloquiums we have been able to get to know each other. The researchers are all in the initial stages of developing their research plans and these will be presented later on in this report. We look forward to following their progress in the years to come.

Visibility has been a priority for us, and we have taken advantage of every opportunity we have gotten to promote the SFI. We have amongst other things been the main attraction on an "NTNU evening" at Dokkhuset in Trondheim and presented during the student festival "UKA". We got the opportunity to present the SFI again when the Dutch Royal Couple visited Norway, accompanied by the Crown Prince and Crown Princess of Norway.

I wish to take this opportunity to thank our partners and researchers for their efforts in 2021 and look forward to moving into 2022 with innovative ideas and collaborative research!

Professor Mary Ann Lundteigen
Centre Director SFI AutoShip

Chairman of the Board

2021 was an eventful year for SFI AutoShip. Despite the pandemic with its many restrictions, the Centre managed to arrange "The SFI AutoShip Days".

This was the first opportunity for our partners to meet in person since the Centre opened! Almost 60 participants met physically while others followed the event online. During these days the participants got to know the researchers and go on site visits to some of our partners. My impression is that this event contributed to good networking between partners, the possibility to be introduced to the PhD candidates that have been hired and to see some actual demonstrations and presentations of test vessels available in Trondheim.

The pandemic has been a challenge for everyone. From a business perspective it has meant that there has been limited opportunities for industry partners to meet and work closely together with the researchers and students. It is very impressive that despite these constraints,

SFI AutoShip has gone ahead with the planned activities, involving the partners online and recruiting new researchers. I would also like to point out good progress in many work packages including definition of several good use cases.

My hope for 2022 is that we will start to see fantastic results from all the excellent PhD candidates, Master projects and researchers according to the ambitious but realistic work plan. So, a great thanks to the management and the rest of the SFI organization for excellent work in a challenging year!
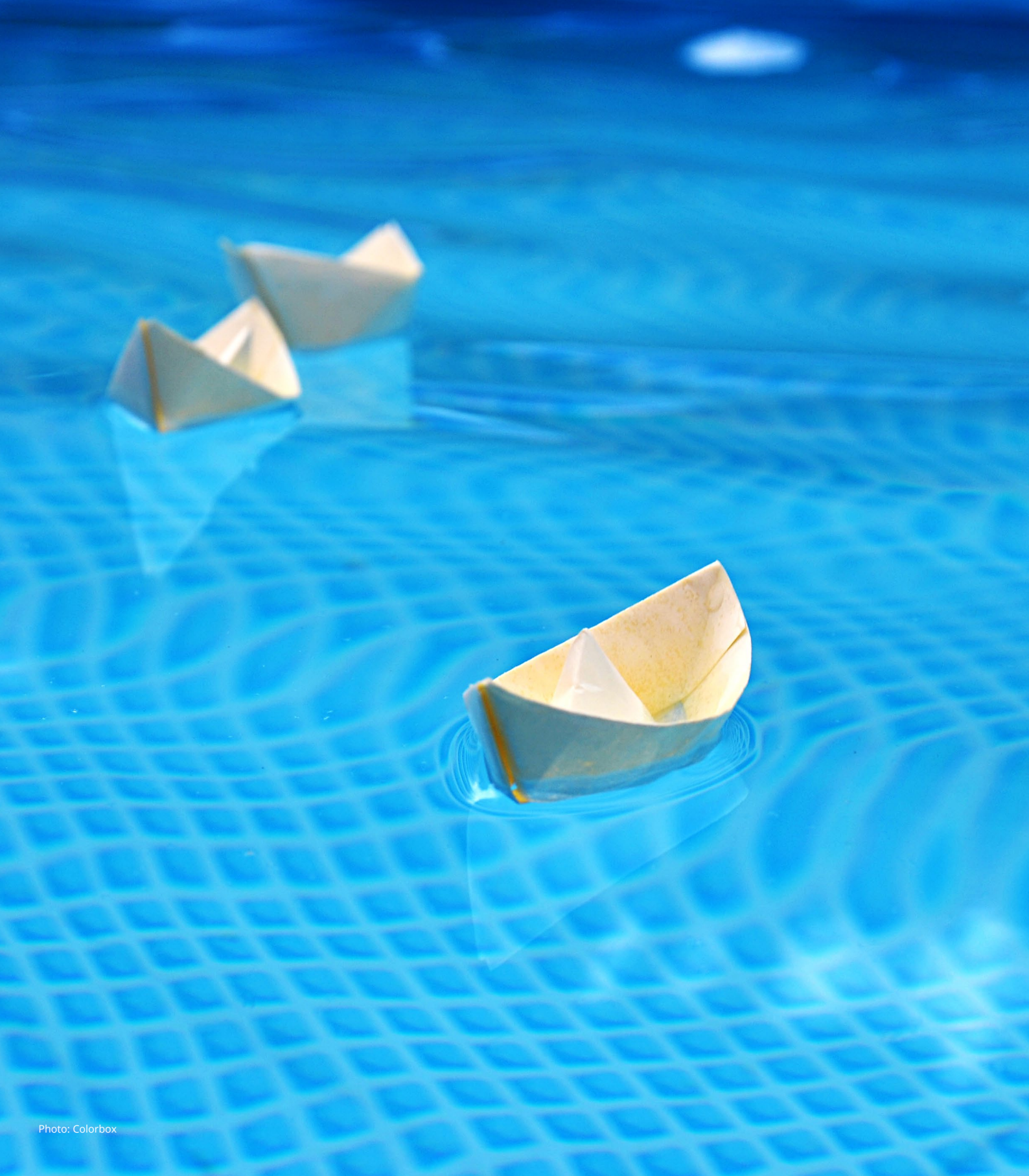
Sverre Rye Torben
Key Technology Owner
Emerging Project department of Kongsberg Maritime
Chairman of the Board of SFI Autoship
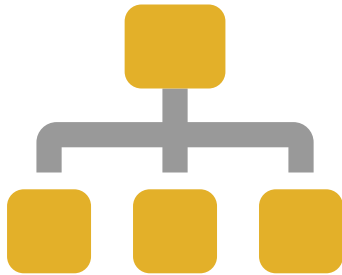
SFI Autoship

Facts **2021**

8

WORK PACKAGES

23 PARTNERS

PhD

PostDoc

Organisation

The Centre is hosted by the Department of Engineering Cybernetics (ITK) at the Faculty of Information Technology and Electrical Engineering (IE), NTNU.

The Centre organisation includes the Centre board, Centre management, eight Work Packages (WPs), and two advisory committees. In total, NTNU involves six Departments in three Faculties: IE faculty: ITK, Department of Electronic Systems (IES), and Department of ICT and Natural Sciences (IIR). Faculty of Engineering (IV): Department of Marine Technology (IMT) and Department of Ocean Operations and Civil Engineering (IHB). Faculty of Architecture and Design (AD): Department of Design (ID).

The other research partners are SINTEF Ocean, SINTEF Digital, Institute for Energy Technology (IFE), and the University of Oslo (UiO).
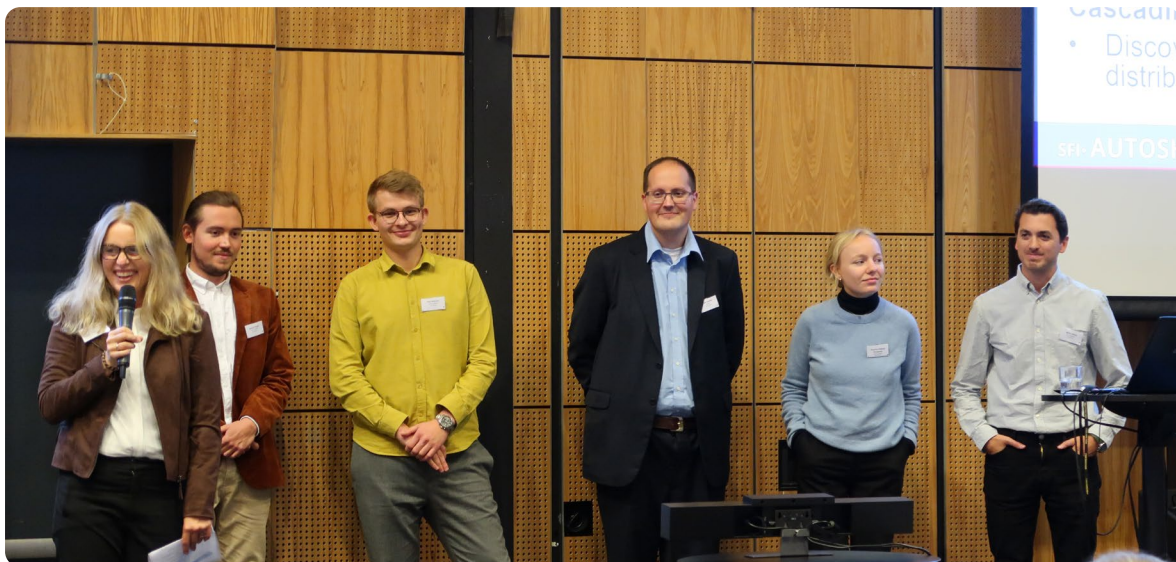
Centre Director Mary Ann Lundteigen with some of the PhDs and postdocs in SFI AutoShip.
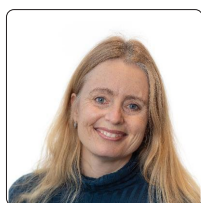
Scientific Advisory Committee Leader
Thor I. Fossen, NTNU

SFI Autoship Centre Board Chairman
Sverre Rye Torben, Kongsberg Maritime

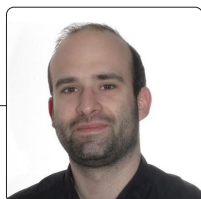**Innovation and Commercialisation Advisory Committee Leader**
Kjetil Skaugset, Equinor

Centre Director
Prof. Mary Ann Lundteigen

Project Coordination
Elisabeth Strand Vigtel

Financial Adviser
Steve Løkkeberg Harila

Anastasios Lekkas, 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
Mary Ann Lundteigen	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
Elisabeth Strand Vigtel	Dept. of Engineering Cybernetics, NTNU	Administrative Coordinator

CENTRE BOARD

Name	Institution	Function
Sverre Rye Torben	Kongsberg Maritime	Chairman of the Board
Kjell Røang	Forskningsrådet	Observer
Ingelin Steinsland	NTNU	Board member
Trond Solvang	UiO	Board member
Trond Runar Hagen	SINTEF AS	Board member
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Jonathan Harcourt	G2 Ocean	Board member
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Svein David Mehaug	Sjøfartsdirektoratet	Board member
Terje Meisler	Trondheim Havn	Board member
Kjell-Inge Stellander	Trondheim kommune	Board member

INNOVATION AND COMMERCIALISATION ADVISORY COMMITTEE

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

SCIENTIFIC ADVISORY COMMITTEE

Name	Institution	Function
Thor I. Fossen	Dept. of Engineering Cybernetics, NTNU	Leader

Other members to be announced

Illustration: Bjarne Stenberg/ NTNU

Research and Work Packages

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

• How can the 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.

In SFI AutoShip we have 8 Work Packages and on the following pages you will get a taste of what research activities that have been done so far in order to achieve our main goals.

1 AutoRemote

WP leader: Associate Professor Anastasios Lekkas (interim leader) and Associate Professor Edmund Førland Brekke, 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.

This WP will solve open problems in the development of technology for solutions to the use cases and will provide benchmarking solutions and data sets. The work in WP1 can be divided into two main tasks, covering the perception side and the actuation/decision-making side of MASS technology.

Photo: Sander Furre

PhD Emil Martens

Multi sensor detection for autonomous surface vehicles

Background and motivation for the research

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

Objective and main tasks

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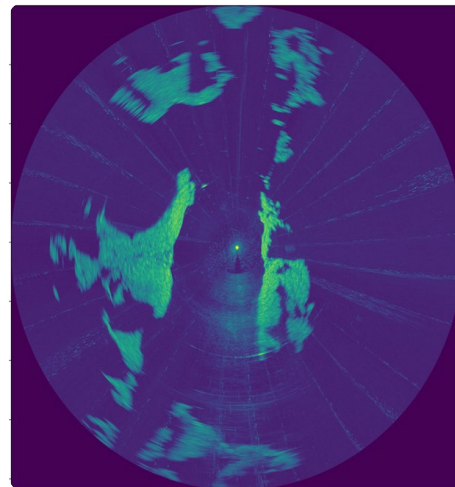
Henrik Dobbe Flemmen

Simultaneous localization and mapping (SLAM) for autonomous ships

Background and motivation for the research

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

Objective and main tasks

The objective is to develop algorithms to solve SLAM for autonomous ships. This will be a combination of adapting existing SLAM algorithms made for other platforms for ships and creating new solutions. The different algorithms will be implemented and tested on recorded data. The goal is to create an algorithm which solves SLAM for ships to a sufficient degree. This could then be implemented into existing products or be used in new products by the industry partners.

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

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

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.
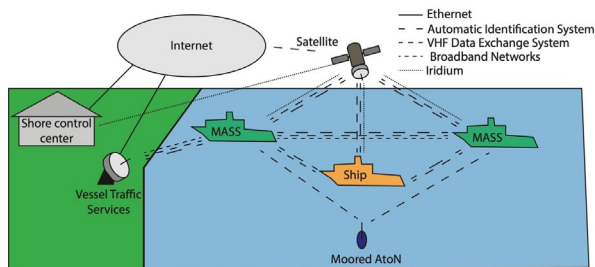

Photo: Sander Furre

Melih Akdağ

Collaborative Collision Avoidance for Autonomous Ships

Background and motivation for the research

Collision avoidance algorithms for autonomous ships can be grouped as global and local path planning algorithms related to the spatial coverage. Global path planning algorithms aim to find optimal routes between two points while considering lands, shallow waters, and environmental forces. Local path planning algorithms consider autonomous ship's dynamics, other ships and navigational rules (COLREGs) to calculate collision-free trajectories. Although there are numerous algorithms for autonomous ships, there is little emphasis on collaboration and communication between ships to solve collision avoidance problems.

In future maritime traffic, autonomous and conventional vessels will co-exist. Therefore, autonomous ships need to communicate and exchange information between other ships, vessel traffic services (VTS), shore control centers, and Aid to Navigation (AtoN) devices such as light buoys. We believe the route exchange method which is supported by the International Maritime Organization (IMO) can be used for designing a collaborative collision avoidance algorithm for autonomous ships. Additionally, active communication between ships can enable us to implement more COLREGs rules to autonomous ship algorithms, e.g. rule 18 on responsibilities between vessels.

The objective of our study is to design a collaborative collision avoidance algorithm that will enable the autonomous ship to negotiate with other ships and shore facilities for collision-free paths.

Research approach/ methodology

To obtain our main goal, the research methodology is divided into objectives as follows:

• Conducting a systematic literature review to investigate previous studies related to collaborative collision avoidance for autonomous ships. Categorizing different approaches, e.g., centralized, decentralized, level of communication, and investigating useful methods which can be applied in the research
• Proposing a high-level procedure to identify collaboration process between ships
• Developing a collaborative collision avoidance algorithm for autonomous ships and evaluating its performance with computer simulations
• Validating the performance of the developed algorithm with multiple autonomous and human-operated ships at sea trials

Expected results and innovations

We expect to enhance navigational safety by enabling interaction between autonomous and human-operated ships. The algorithm will be developed considering container ships navigating in fjords, ports, and hinterland. We will be in collaboration with the partners of the Use Case 2 Short Sea Container Shipping.

An overview of relevant actors and communication technologies in the maritime environment.
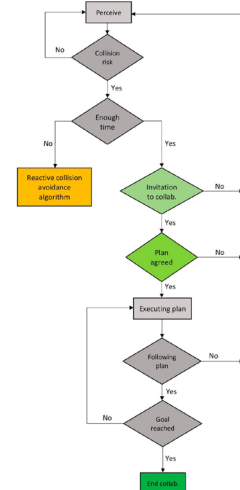
The proposed high-level procedure for the collaborative collision avoidance algorithm.

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3

Remote Operation Centres (ROC) and Human factors

WP leader: Associate Professor Ole Andreas Alsos (formerly Professor Thomas Porathe)

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 among MASS-ROC and conventional ships will depend heavily on sensor and AIS information, as well as cooperation with the vessel traffic service (VTS).

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

In 2021 Work Package 3 has onboarded 3 PhD students and graduated 2 master students related to the SFI. Two papers have been published, a PhD seminar has been held at IFE and they have had 3 popular science presentations. In addition, the Work Package leader has received funding for «Mennesket i fremtidens havromsoperasjoner» (MIDAS) (NFR Kapasitetsløft), which will be a dissemination platform for SFI AutoShip. All these activities have contributed to reaching the Centre's objectives in 2021.

Andreas Solnørdal Madsen

AI decision transparency in autonomous shipping

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

Objective and main tasks
The goal of this PhD is defined as "Developing strategies for AI decision transparency in autonomous shipping" The main research question for the PhD is defined as:

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

RQ1: How can decision transparency in an AI system be defined and what is the state-of-the-art research within the concept traffic alert and collision avoidance systems with respect to decision transparency?

RQ2: What is required to enhance decision transparency in an AI system with respect to autonomous shipping?

RQ3: What strategies can be used to enhance and maintain the situational awareness of a remote operator?

Research approach/ methodology
**For RQ1** a state-of-the-art literature review will be carried out to facilitate the process of finding suitable measures to ensure safe operations of marine surface ships in the context of decision transparency for a remote operator.

For RQ2 stochastic models (e.g. cluster analysis) and XAI will be used to model when an autonomous system should be in autonomous mode, and when to raise a red flag to alert a remote operator. The focus will be on which attributes should be monitored and which metrics should be used as a basis for the machine learning algorithms.

For RQ3 distributed situational awareness (DSA) theory will be utilized in exploring the possibilities of enhancing the collaboration between an AI system and the crew/remote operator.

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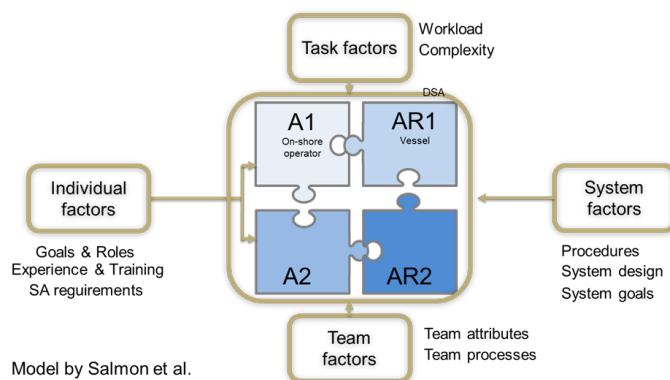
Model by Salmon et al.

Felix-Marcel Petermann

Interaction Design for Autonomous Ships

Background and motivation for the research
My educational background includes a Bachelor of Applied Life Sciences and computer science courses, as well as a master's in human computer Interaction and Social Media from Umeå University. I formerly worked as a User Experience and Interaction Designer at an industrial design studio, where I contributed to projects in areas such as transportation, construction, and medical. In the SFI, my study will focus on Interaction Design, specifically the design of various interfaces in a Remote-Control Center, as well as the communication and interaction between the autonomous and the humans in this project.

Objective and main tasks
The objective is to contribute to the future of a contemporary, safe, and sustainable marine environment by establishing an atmosphere in which people and robots may operate together.

In the maritime industry there are varying degrees of autonomy, where human operators monitor and manage the ships. Therefore, a shore control centre is required. Control room designs for power plants, oil platforms, and traffic control centres for road, rail, and air traffic are common. But none of them focus on autonomy. This means the operator is watching a static scene or a small, defined piece of the ecosystem. Current control room structure and methods may not work in an autonomous setting and need more study. We need to look at how operators can monitor and run MASS, as well as how burden may be dispersed.

Research approach/ methodology
The goal is to identify which sensor and media types are now in use, which inputs are useful or have a negative influence on user engagement, performance, or behaviour. A second step will be to examine how present control rooms employ different information sources. Observations and interviews will help me determine which information sources are useful and which are not. In a later step, the plan is to simulate different media combinations and examine their impact on situational awareness and connect them to different personality types.

Expected results and innovations
After the first phase it is planned to create different interfaces for information display for certain situations with a focus on alert design and make the decision of the AI more comprehensible.
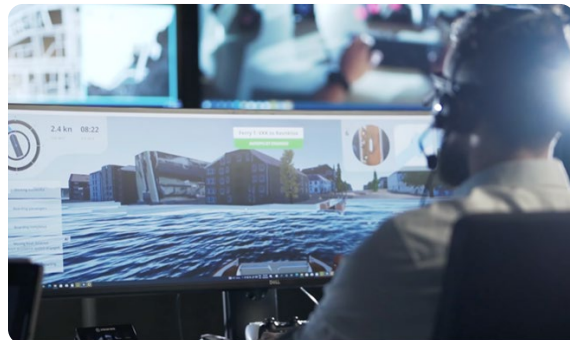
An operator is working on solving tasks in the Shore Control Lab (SCL). Photos by Nicholas Lund (Videomakeriet)

Eirik Fagerhaug

Explainable AI for Autonomous Ships

Background and motivation for the research

With a bachelor's degree in software engineering and a master's degree in Simulation and Visualization (including an exchange year in Germany, focusing on robotics), my background is relatively broad. I have been working a couple of years as a developer/consultant; on one project for Rolls-Royce Marine and one larger analytics project. Starting on a Ph.D. allowed me to use more of my academic specialization, which has been a desire since graduation.

Objective and main tasks

Autonomous ships will be dependent on shore-control centers (SCCs) for the foreseeable future. The role of the SCC will be to monitor the vessel(s) and "intervene" if necessary. My objective is to research methods to explain the actions of some "black-box" models that have been popular to use on autonomous systems lately. The goal is to prevent situations that can lead to accidents without the operator knowing what is going on.

Research approach/ methodology

The research will, in the beginning, mainly be done using a simulator connected to a separate computer (acting as a control center). A simulation will make it easier to test multiple different methods over a shorter timeframe. I will also do field research to see how operators work on other control centers (e.g., trains, airports, or power plants). I also hope to be able to test my research on an actual vessel and not only in a simulation.

Expected results and innovations

The research should result in more knowledge on the explainability of "black-box" systems and their usability in autonomous ships. There will also be a prototype of an example of such a system.
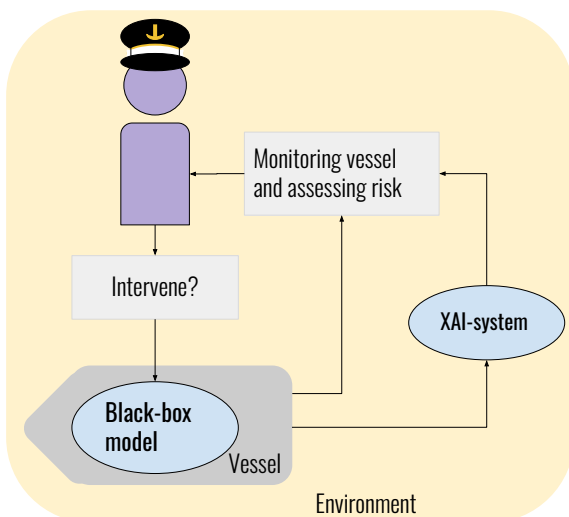

Figure from article "Explaining a Deep Reinforcement Learning Docking Agent Using Linear Model Trees with User Adapted Visualization" by Gjærum, Strümke, Alsos and Lekkas

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 will focus on risk reduction, mitigation strategies, and safe solutions for the design and operation of autonomous ships. This achievement relies on the ability to identify the new risks and incorporate necessary (technical, software, security, human and organisational) measures into the systems, the operation, and the associated infrastructure. In 2021 we onboarded 4 PhDs and 1 postdoc and conducted a webinar on Autonomous Ships and the Law hosted by our partners at The University of Oslo.

Foto: Trond Johnsen/SINTEF

Susanna Dybwad Kristensen

Online risk modelling of autonomous ships

Background and motivation for the research

Autonomous ships are under development, however, risks must be assessed and controlled before these can be put into operation. During operation, autonomous ships will be subjected to dynamic factors, such as degrading technical equipment and changing environmental factors. These factors may affect the risks during operation, and needs to be considered in the decision-making, performed either by the human operators or the system itself. This introduces the need for online risk modelling. Online models utilize different sources of data to estimate the risks related to autonomous ship operations, in order to support decision-making for safer and more efficient operations.

Objective and main tasks

The objective of the PhD work is to research and develop online risk models for autonomous ships. The first main tasks will be to identify hazards related to autonomous ship operations, both with respect to safety and security. The second main task is to use the identified hazards as input to the risk model development. The risk model output will be adapted to be used as input for the autonomous ship control system. A third main task is to test the risk models and assess the effect on operational decision-making.

Research approach/ methodology

Both qualitative and quantitative methods will be used in the research. For hazard-identification, the qualitative method system-theoretic process analysis has been applied to autonomous ship operations. Autonomous ship control systems require quantitative input, and the risk models must fulfill this requirement. System simulation will be an important tool for assessing the applicability and efficiency of the risk models. Testing the models on real systems, such as smaller unmanned surface vehicles, is also a goal.

Expected results and innovations

The expected result from the research is new models for the operational risk of autonomous ships. This will include the identification of safety- and security-related hazards for autonomous systems and operations. Further results include the development of operational safety envelopes, related to the use cases in the SFI, and according to stakeholder specifications.

The AutoNaut USV has been used for case studies in the PhD research. Photo by A. Dallolio, NTNU.

Raffael Wallner

Safety Demonstration of Autonomously Controlled Ships using Digital Twin

Background and motivation for the research
Safe operation is a crucial requirement for autonomously controlled ships. However, assuring safety under all conditions and circumstances is not a straightforward task due to the complexity of such systems. Furthermore, the self-learning and evolving characteristics of autonomous systems require to evaluate the safety during the whole life cycle and not just during design. An approach to test and verify safety in any state are safety demonstrations for potentially risky situations in simulations using a digital twin. Digital twins have been used in different domains for several years now but approaches to represent autonomous systems with digital twins started only recently. Particularly for the application of safety demonstrations of autonomous ships, requirements regarding, e.g., functionality, fidelity and scope of the digital twin have to be further elaborated.

Objective and main tasks
The main objective of this PhD project is to develop a digital twin that can be utilized to demonstrate safety of autonomous ships. Based on these safety demon

strations it should be possible to evaluate the safety of the autonomous system as well as later evolvement, modifications or actions during the operational phase.

Research approach/ methodology
First, research has to be done in order to collect requirements for digital twins representing autonomous ships. Then structures, more detailed specifications and interfaces are defined. Based on the gathered information and elaborated research results, an implementation of a digital twin can be developed. The functionality of the digital twin then needs to be tested and verified. Figure 1 shows a possible structure of a digital twin in order to evaluate the behaviour of an USV during an operation.

Use-case involvement and industry collaboration
Scenarios for the research project will focus on use-case 4, i.e., offshore support operations including unmanned surface vehicles (USV) in combination with autonomous underwater vehicles (AUV) or remote operated vehicles (ROV). Research will be done in collaboration with industry partners of the according use-case.
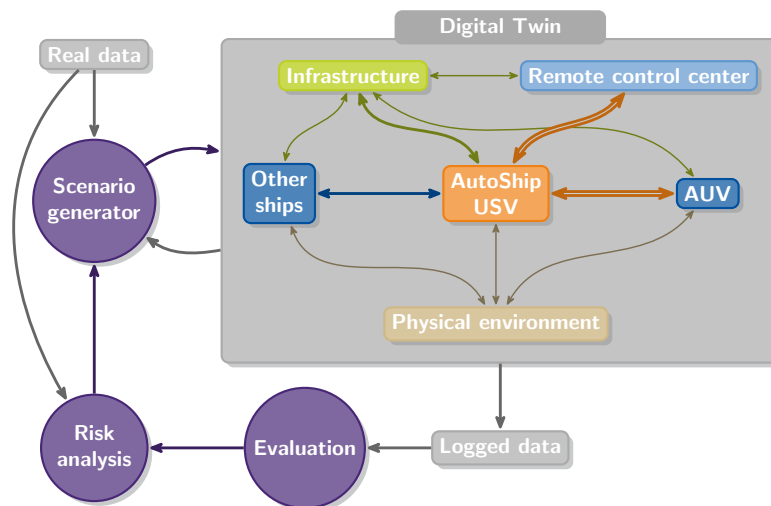
A possible structure of a digital twin in order to evaluate the behaviour of an USV during an operation.

Spencer A. Dugan

Reliable design and operation of propulsion systems for autonomous ships

Background and motivation for the research
Two of the dominant current trends in the maritime industry are the electrification of propulsion plants and reduction of manning in the mission towards autonomous ships. Electric propulsion plants may suffer from complex failure modes and require complicated planned and unplanned maintenance actions. In addition, a critical failure of the propulsion plant at sea creates unsafe conditions that may lead to loss of life and/or damage to the ship and environment.

Objective and main tasks
This work investigates the reliability and safety of various propulsion systems in the absence (or reduction) of crew. This is explored in two ways. First, the events contributing to a loss of propulsion are modeled for various propulsion system types and configurations. The systems are simulated to understand the dynamic conditions and failure modes. Secondly, the consequences of propulsion loss are explored. The two consequences of primary focus are stability failure and drifted grounding.

Research approach/ methodology
The first phase of the work relies upon both qualitative and quantitative methods for risk assessment. STPA and FRAM are used to understand complex systems with emergent properties. Equipment simulations are performed to assess system reliability and failure modes. The second phase uses hydrodynamic and maneuvering models to simulate the stability characteristics of the vessel, and an analysis of historical accident and operational data to predict drifted groundings.

Expected results and innovations
The research will demonstrate the feasibility and operational limits of different propulsion systems for autonomous vessels. In addition, safe design and operation principles based on ship type and operating profile are expected. Lastly, the simulations of the dead-ship condition are expected to improve the understanding of IMO's proposed second generation stability criteria.
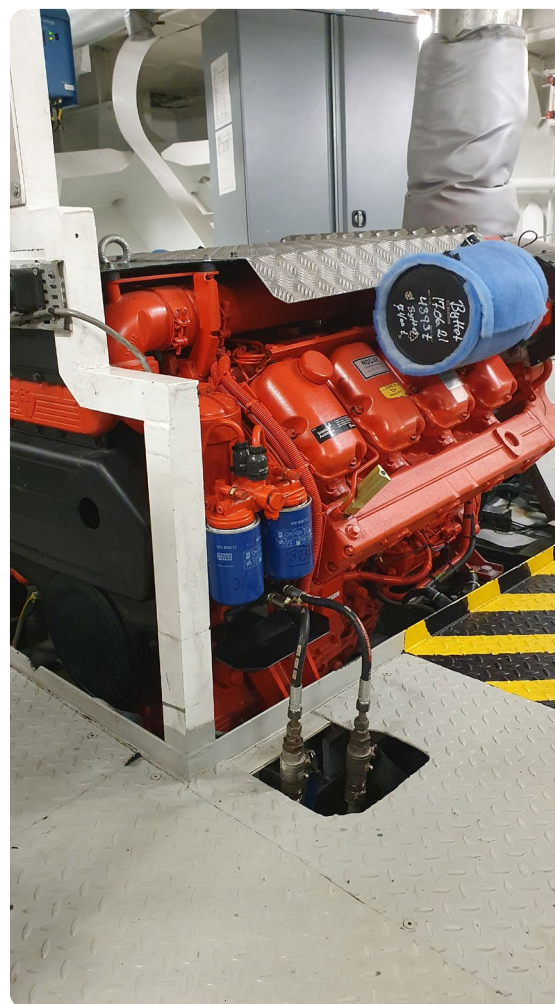
From the machine room of a ferry. Foto: Trond Johnsen/SINTEF

Ayoub Tailoussane

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

Background and motivation for the research
After obtaining a Bachelor's in Private Law and a master's degree in Business Law, I worked as a Legal Counsel with the law firm CMS Francis Lefebvre Morocco for over two years. I went on afterwards to complete an LL.M. in Admiralty & Maritime Law at Tulane University in New Orleans, Louisiana, USA.

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

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

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

Through a legal analysis of the COLREGS which focuses on their interpretation and application by courts, the research seeks to contribute to the development of navigationally-autonomous vessel by proposing a legally-substantiated explanation of the applicable rules. The exercise will necessarily serve to highlight the potential difficulties in the strict application of the COLREGS to all or certain categories of autonomous vessels, which puts it also in a good position for participating in potential discussions and efforts for possible amendments and/or redrafting of the collision regulations to take into account the idiosyncratic differences between traditionally manned and autonomous vessels.

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

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

Alojz Gomola

Risk role in autonomous ship software systems

Background and motivation for the research
I have a background in the development of safe software approaches for high-level autonomous functionality like reasoning and deliberation. The safe and secure software provides reliable functionality of the system. Still, it also guarantees the correctness of operation and prevents harm to possible risk subjects. I also have industrial experience with embedded systems for banking and insurance for five years, software development and architecture in railway and aviation transportation systems for another five years, focusing on safe and secure functionality development. In terms of education, I have a Masters' degree from the Slovak University of Technology in Software Engineering and a doctoral degree from the University of Porto in Applied Mathematics.

Objective and main tasks
Software risk in the maritime environment is in the early stage of development and understanding. The existing practices are coming from the automotive and railway industries. Those approaches are restrictive in terms of high-level autonomous functions. There is a need for:
1. Development of software risk and failure taxonomy to classify and quantify risk coming from software parts of the complex maritime system.
2. Integration of software risk into existing methodologies for ship operation risk assessment and prediction.
3. Design of preemptive and permissive countermeasures which provide risk reduction and reliability

increase with the feasibility of practical and economical implementation in existing software development and validation processes.

Research approach/ methodology
- Modeling system in UML, BPMN, and SysML, creating Temporal and Structural views of autonomous ship software systems focusing on function safety and reliability.
- Development and application of risk-based techniques to autonomous ship software, including rapid prototyping in Matlab/Simulink/Python.
- Synthesis of new and application of existing process management and development approaches for software development.

Expected results and innovations
- Taxonomy for software failure classification on a system, subsystem, code, and integration level provides risk-driven software development and functionality design, reducing development time and cost.
- Safe, secure, and scalable software architecture for autonomous ships - integrating existing and new subsystems into a scalable framework, covering many maritime autonomous surface ships' deployment configurations.
- The case study of autonomous ship software risk applies taxonomy on real autonomous software preferably related to the reason and deliberate autonomy stage. Proposing safety and reliability improvements.
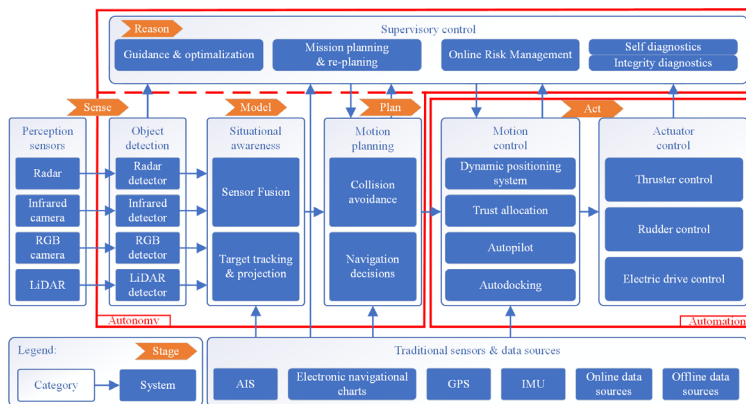
Functional overview of autonomous ship software systems

5 Sustainable Operations

WP leader: Senior project manager, Odd Erik Mørkrid (formerly Senior Researcher Ørnuf Jan Rødseth, SINTEF Ocean)

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

Autonomous ships can dramatically change transport systems, e.g. by introducing smaller and more flexible vessels. This may be a key factor in reaching IMO's 50% goal for emission reductions by 2050 as well as other sustainable development goals. The sustainability of an autonomous ship system will depend on efficient utilization and integration of all technologies developed in the Centre. The future auto-remote solutions must be aligned with the human capabilities of any remote operators and other mariners; automated berthing, 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.

WP5 will provide the integration among the technologies developed in WPs 1-4 with the transport operations undertaken, physical port automation systems and economic and environmental optimization. The WP will provide quantified evidence that the use cases developed in SFI AutoShip will be cost-effective as well as environmentally significantly better than alternatives used today.

Terminology standard

The objective of this task was to establish a ***Committee Draft for Voting*** (CDV) of ISO 23860 MASS terminology "ISO/TS 23860 Ships and Marine Technology – Vocabulary related to autonomous ship systems" contains definitions related to MASS and other types of autonomous ship systems. It was developed by ISO TC8/WG10 with Ø. J. Rødseth as project leader and has been supported by SFI AutoShip and other related projects. It was finished from the working group in December 2021 and is now in the process of being published as a technical specification from SIO.

Key performance indicator (KPI) definitions

The objective of the task is to establish a set of KPIs for use in assessment of the viability of new autonomous ship systems. The work with KPIs is linked to other projects like the EU Horizon 2020 projects AUTOSHIP and AEGIS and was somewhat delayed due to this connection. However, one workshop was held together with partners in September 2021, where a first set of proposed KPIs was established for use case 2 short-sea container shipping. The focus areas from the use case, «Autonomous vessel design and operations, including auto-docking and auto-mooring", "Improved logistics, including port and hinterland" and "Onshore control centre and communication ship-shore" were starting points for the brainstorming at the workshop. Further workshops will be arranged.

Cargo handling state-of-the-art and gap analysis

Three workshops, "Why automate", "State-of-the-art" and "New technologies and technological gaps" were arranged together with SFI Autoship partners with an external presentation by Yara in the last workshop. These workshops, interviews and market research constituted the content of a report on cargo handling gap analysis. This report will recommend research areas that will be further investigated within work package 5, related to cargo handling automation.

6

Use Case

WP leader: Research manager Trond Johnsen, SINTEF Ocean

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

The objective of the use case is three-fold, where the use case will:

1. Provide direction and prioritization for relevant topics tied to the use case applications areas in focus

2. Be the common ground for dedicated use case workshops where the purpose is to mature requirements, needs and central technology gaps

3. Serve as an arena, through connected infrastructure, for testing and demonstrating research results and identify topics which require further research and innovation.

Each use case will involve at least one end user, product and service providers, research institutes, universities and authorities, which represent the entire research-innovation chain as well as competence at all technology readiness levels (TRLs). At the start of the Centre, four use cases have been identified as most promising from the industry-partners' perspective. The typical duration of the use cases will be 2-3 years with activities for each of the three use case objectives. Regarding objective 3, PhD/PD and other research activities will plan for deployment of the results in collaboration with involved partners. When the focus areas of the use case have reached a sufficiently high TRL, these will be handed over to the industry partners for further development internally and/or through new and dedicated research and innovation projects. There are four use cases. In 2021 Several workshops have been arranged in each of the 4 Use Cases, resulting in Use Case Scope Specification documents that describes state-of-the-art, focus areas and main activities for each Use Case.

Photo: Piotr Lewandowski and G2Ocean.

Use Case 1: Deep-sea bulk shipping
This use case is led by the SFI partner G2Ocean. G2Ocean has identified target areas that could benefit from automation related to cargo handling such as cargo hooking and lifting, crane handling and synchronization of two or more cranes. In addition, the use case will look at how and if one can enable periodically unmanned bridge during overseas sailing.

Photo: North Sea Container Line (NCL)

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

Photo: Torghatten/NTNU

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

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

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. Training of young researchers, facilitating ideation, and monitoring potential for exploitation of research outcome will be elements in the innovation management within the SFI.

The Centre's first year has been characterized by start-up activities and recruitment. As part of the start-up activities, we have focused on how to facilitate and stimulate for innovation. The SFI has established an Innovation Strategy which encompasses an innovation model, strategy for the exploitation of results and formal procedures in relation to intellectual property rights. We have initiated a so-called "School of Inno-vation", offered to the Centre's PhDs and postdocs in the form of regular colloquiums. The goal is amongst other things to raise awareness on how research results can be applied to specific Use-cases and to introduce tools for the generation of ideas in an early phase. In 2021 activities have included colloquium and workshop on introduction to IPR and useful tools for function analysis in the problem definition phase.

Odd Ivar Haugen from DNV explains in the workshop on functional analysis. Photo: Kjell Olav Skjølsvik

Illustration: Bjarne Stenberg/ NTNU
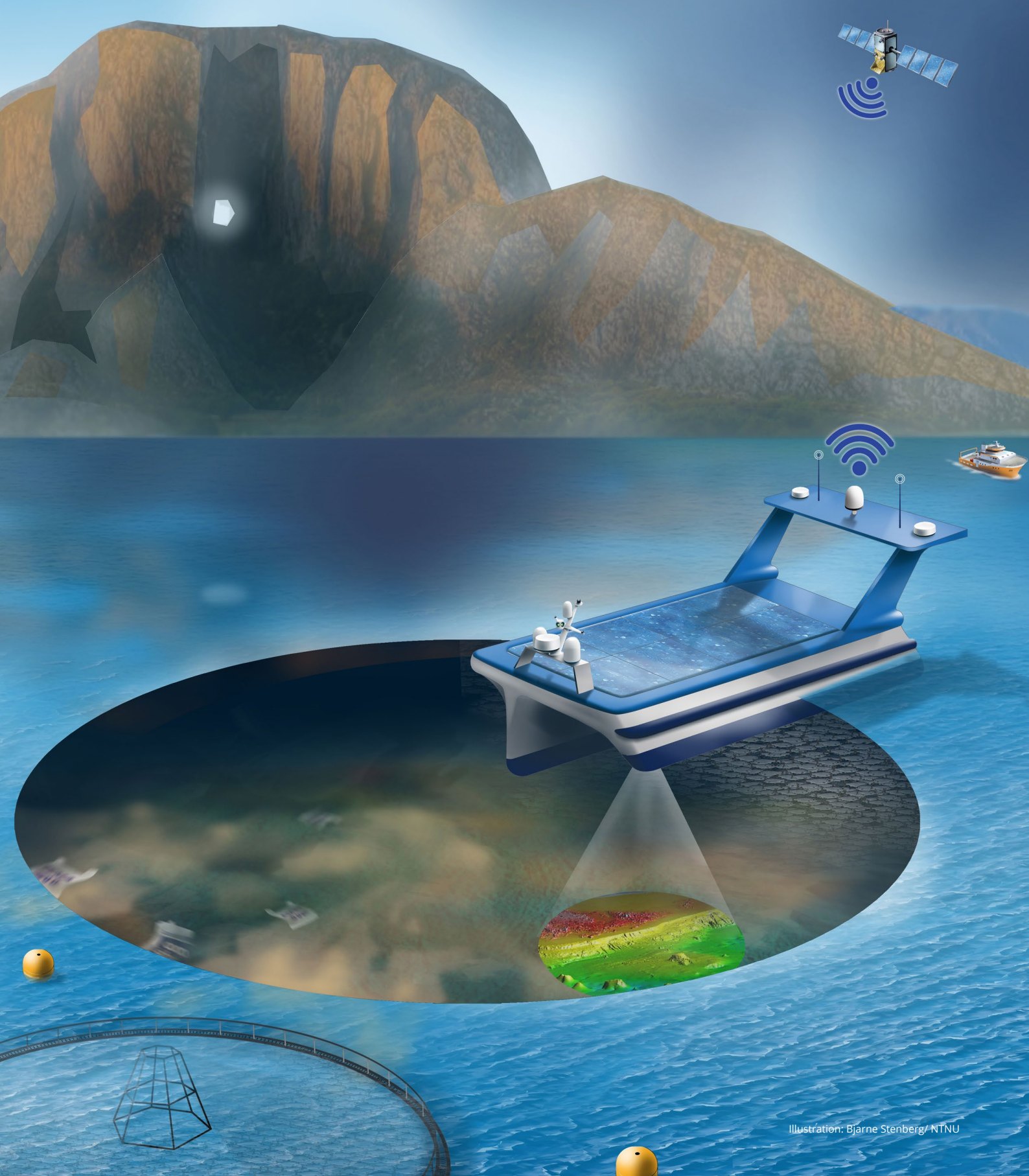
International Collaboration

The international collaboration in the SFI builds on existing partnerships and our participation in international research groups, projects and forums. In 2021 we have collaborated with UCLA in connection with the postdoc in work package 4. We have had several interesting discussions on the subject of software risk which is highly relevant to autonomous ships.

In addition to being the Work Package leader of WP 5, Odd Erik Mørkrid is also coordinating the EU Horizon 2020 project AEGIS, which objective is to design a new waterborne logistics system that will attract cargo which is being transported on road by trucks today. SFI AutoShip partners such as NCL, Trondheim Havn and MacGregor are also part of this project and one of the use cases is investigating short-sea container shipping and how a feeder loop consisting of so-called mother and daughter vessels can make waterborne transport the preferred transport mode in the region. Focus is both on the vessels, terminal operations and cargo handling equipment such as cranes.

In addition to AEGIS, SFI AutoShip is also closely connected to the EU project AUTOSHIP through the participation of several parties in the SFI. This also applies to the international activities undertaken jointly by these projects. Of particular interest is the following achievements:

1. "ISO/TS 23860 Ships and marine technology — Vocabulary related to autonomous ship systems" have no been completed from ISO TC8/WG10 and now waiting for publication. The standardization work was led by SINTEF Ocean. This standard was also brought to the attention of IMO as input paper MSC 103/5/3, 15 March 2021.
2. Work will continue in ISO on a proposed protocol specification between RCC and MASS.
3. The International Conference on MASS (ICMASS 2022) will be held in Singapore, April 6-7, 2022 together with MTEC 2022. SINTEF Ocean and NTNU are in the organization committee, which is being led by MPA in Singapore. About 40 international papers on MASS will be presented, of which a significant part are from Norway.
4. The Third International Ship Autonomy and Sustainability Summit will be held in Oslo, together with Nor-Shipping on April 5, 2022. SINTEF Ocean is responsible for the summit, but it is co-organized with Nor-Shipping and EU's DG MOVE. Last virtual summit in Brussels in November 2020 attracted close to 700 attendees.

The Centre Director has taken the initiative to have NTNU become a member in EU's "Waterborne Technology Platform". We expect that this membership will contribute to increased activity between NTNU and the other members and that this has been a catalyst for the collaboration between NTNU and the EU within the maritime sector.

OUR TOP INTERNATIONAL RESEARCH PARTNERS

Prof. Ali Mosleh
UCLA

Prof. Andreas Molisch
University of South California

Prof. Peter Willet
University of Conneticut

Prof. Athina Petropulu
Rutgers university

Prof. Rudy Negenborn
Delft university

Prof. Jose Neira
University of Zaragoza

Assoc. Prof. Tim Miller
University of Melbourne

Recruitment

In 2021 we recruited 10 PhDs and one postdoc to the Centre

Name	PhD project	Work package	Supervisor	Host department
Melih Akdag	Collaborative collision avoidance for autonomous ships	2	Tor Arne Johansen	Inst. for teknisk kybernetikk (ITK), NTNU, Gløshaugen
Henrik Flemmen	Non-GNSS localization for USVs (aka SLAM	1	Edmund Brekke	ITK, NTNU, Gløshaugen
Emil Martens	Multi-sensor object detection and classification	1	Annette Stahl	ITK, NTNU, Gløshaugen
Felix Peterman	Interaction design	3	Ole Andreas Alsos	Inst. for Design, NTNU, Gløshaugen
Andreas Solnørdal Madsen	AI decision transparency in autonomous maritime operations	3	Magne Aarset	Inst. for havromsoperasjoner og byggteknikk, Ålesund
Eirik Fagerhaug	Explainable AI for Autonomous Ships	3	Ottar L. Osen	Inst. for IKT og realfag, Ålesund
Susanna Kristensen	Online risk modeling of autonomous ships	4	Ingrid B. Utne	Inst. for marin teknikk, Tyholt Trondheim
Spencer Dugan	Risk acceptance and operational constraints in risk modeling of autonomous operations	4	Ingrid B. Utne	Inst. for marin teknikk Tyholt Trondheim
Alojz Gomola	Dynamic and simulation-based risk modeling for operational decision support and verification	4	Ingrid B. Utne	Inst. for marin teknikk Tyholt Trondheim
Ayoub Tailoussane	COLREGS and their connection with autonomous vessels	4	Trond Solvang	Nordisk institutt for sjørett, UiO
Raffael Wallner	Safety demonstration of autonomous control systems using digital twin	4	Mary Ann Lundteigen	ITK, NTNU, Gløshaugen

Some of the PhDs and researchers visited the ferry connecting Ytterøy to Levanger.

PhD and Postdocs

Emil Martens
Multi sensor detection for autonomous surface vehicles
Supervisors: Annette Stahl,
Edmund Førland Brekke,
Rudolf Mester

Felix-Marcel Petermann
Interaction Design for Autonomous Ships
Supervisor: Ole Andreas Alsos

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

Eirik Fagerhaug
Explainable AI for Autonomous Ships
Supervisors: Ottar L. Osen,
Robin T. Bye, Anastasios Lekkas

Melih Akdağ
Collaborative Collision Avoidance for Autonomous Ships
Supervisors: Tor Arne Johansen,
Thor I. Fossen (Co-sup)

Susanna Dybwad Kristensen
Online risk modelling of autonomous ships
Supervisors: Ingrid B. Utne,
Astrid H. Brodtkorb

Andreas Solnørdal Madsen
AI decision transparency in autonomous shipping
Supervisors: Magne Aarset,
Ole Andreas Alsos

Raffael Wallner
Safety Demonstration of Autonomously Controlled Ships using Digital Twin
Supervisors: Mary Ann Lundteigen
(main supervisor, NTNU)
Tor Arne Johansen
(co-supervisor, NTNU)
Bjørn Axel Gran (co-supervisor, IFE)

Spencer A. Dugan
**Reliable design and operation
of propulsion systems for
autonomous ships**
Supervisors: Ingrid B. Utne (main);
Mehdi Zadeh (co)

Ayoub Tailoussane
**The application of the COLREGs to
autonomous vessels, and the
challenge of translating legal con-
cepts into machine comprehensible
data for the development of COL-
REGs-compliant autonomous vessels**
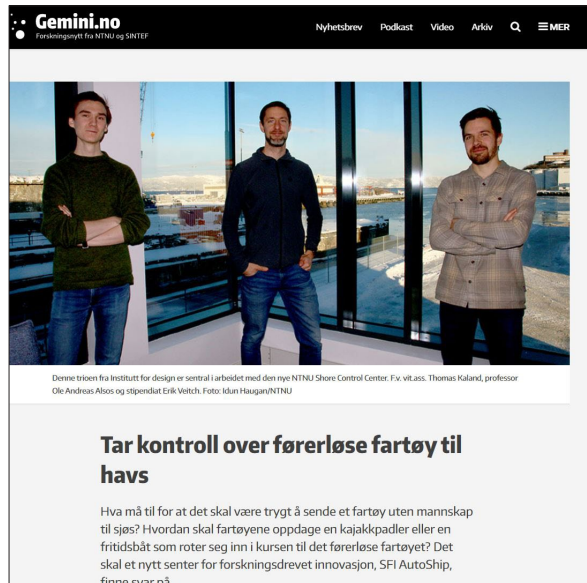Supervisor: Trond Solvang

Alojz Gomola
**Risk role in autonomous ship
software systems**
Supervisor: Prof. Dr. Ingrid Bouwer Utne

Communication

SFI AutoShip in the news in 2021

FROM THE PUBLICATION "RESEARCH NEWS FROM NTNU AND SINTEF

TV 2 NEWS
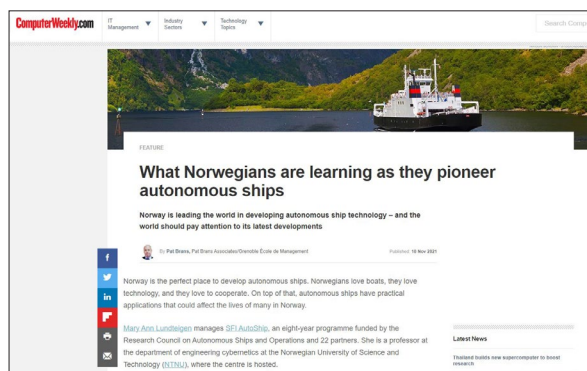
COMPUTER WEEKLY–NEWS AND ANALYSIS WITHIN IT AND TECH

SOCIAL MEDIA 2021

Royal visit from The Netherlands

The royal couple of the Netherlands King Willem-Alexander and Queen Maxima visited Trondheim together with Crown Prince Haakon and Crown Princess Mette Marit of Norway. They visited the localities of Maritime Robotics where SFI AutoShip had set up a stand that they explored. Photo: Julie Solem

Presenting SFI AutoShip on Different Arenas

Espen Barth Eide visited our facilities at Nyhavna. Photo: Elisabeth Strand Vigtel/NTNU

Egil Eide. Photo: M. Sjøholtstrand/NTNU

Mary Ann Lundteigen presents at NTNU Evening. Photo: M. Sjøholtstrand/NTNU

The SFI Days

On September 15 and 16 2021, SFI AutoShip had its first SFI Days. Despite pandemic restrictions, almost 60 participated physically and around 15 digitally. The aim was to meet each other, get to know the new PhDs and get introduced to our research partners. We were lucky enough to get site visits to Maritime Robotics, Kongsberg Maritime and even board the milliAmpere 2. We also had time for two parallel sessions where we went more in depth into the subject of Sustainable Value Creation and KPIs, and Human Factors in Autonomy.

Photo: Elisabeth Strand Vigtel/NTNU

Photo: Sander Furre/NTNU

Photo: Sander Furre/NTNU

Publications 2021

Type	Name/description	Name of journal/ conference/book	Main author
Journal/article	Shipowners: vicarious liability under English and Norwegian law* With an eye to technical failure of autonomous ships		Trond Solvang
	Autonomous ships and the law	Vitenskapelig antologi	Erik Røsæg, Henrik Ringbom og Trond Solvang
	Fremtidig skade ved førerløse biler og skip	Tidsskrift for erstatningsrett, forsikringsrett og trygderett	Trond Solvang og Arne Moss Westgård
	Maneuvering with safety guarantees using control barrier functions	IFAC-PapersOnLine	Mathias Marley, Roger Skjetne, Erlend Andreas Basso og Andrew R. Teel
Conference paper	Autonomous Ships: A research strategy for Human Factors research in autonomous shipping	AHFE 2021	Thomas Porathe
	Human-Automation Interaction for a Small Autonomous Urban Ferry: A Concept Sketch	ESREL 2021 (European Safety and Reliability Conference)	Thomas Porathe
	Synergistic control barrier functions with application to obstacle avoidance for nonholonomic vehicles	Proc 2021 American Control Conference, IEEE conference proceedings	Mathias Marley, Roger Skjetne og Andrew R. Teel
	No-one in control: unmanned control rooms for unmanned ships?	20th Conference on Computer and IT Applications in the Maritime Industries, COMPIT '21	Thomas Porathe
Books/chapters	Introduction	Autonomous Ships and the Law	Trond Solvang, Erik Røsæg og Henrik Ringbom
	Man, machine, and culpa. Or finding a path toward strict liability	Autonomous Ships and the Law	Trond Solvang

Presentations at external conferences and interviews in media	SFI AutoShip- hvordan bidra til trygge og bærekraftige autonome skipsoperasjoner	Ocean Autonomy Conference	Mary Ann Lundteigen
	Design for tillit til autonome systemer	Ocean Autonomy Conference	Ole Andreas Alsos
	Intelligente skip for det grønne skiftet	UKA Technology, conference day	Mary Ann Lundteigen
	Advances in the safety and assurance of autonomous ships	STAB&S (International conference on the stability and safety of ships and ocean vehicles.	Ingrid Bouwer Utne
	What can we learn from others: On the guideline 070 in the oil and gas industry and if we can learn something from this process.	Talk given at ZAWAS project workshop https://sams-norway.no/ partners/zawas-zeroemission-autonomous-watershuttles/	Mary Ann Lundteigen
	Mer fart på grønt skifte i blå transport	Adressa	Ingrid Schjølberg og Mary Ann Lundteigen
	Tar kontroll over førerløse fartøy til havs	Gemini	Mary Ann Lundteigen, Egil Eide, Ole Andreas Alsos og Erik Veitch
	ShipChat: Debate on Safety in Maritime sector	Njord Challenge	Ingrid Bouwer Utne og Edmund Brekke
	NTNU Kveld: Førerløse fartøy: gevinst eller risiko?	NTNU kveld	Mary Ann Lundteigen, Egil Eide og Edmund Brekke
	Slik skal mennesker få tillit til selvkjørende farkoster	MN24 (MidtNorsk Næringsliv)	Ole Andreas Alsos
	Interview: Developing command and control for unmanned vessels	The Maritime Executive	Mary Ann Lundteigen, Egil Eide, Ole Andreas Alsos, Erik A. Veitch
	Panelist: The future of maritime transport is autonomous- or is it? Parallel session III: Digital Oceans	6th NTNU EU conference	Mary Ann Lundteigen
	What Norwegians are learning as they pioneer autonomous ships	Computer Weekly	Frode Halvorsen, Ørnulf Rødseth, Ole Andreas Alsos og Mary Ann Lundteigen
	Human-automation interaction for autonomous ships: Decision support for remote operators	TransNav, International Journal on Marine Navigation and Safety of Sea	Thomas Porathe

Master Students 2021

MASTER STUDENTS OBTAINING THEIR DEGREE ON AN SFI AUTOSHIP TOPIC IN 2021		
Jon Magnus Moen	Automatic control with risk contingencies for autonomous passenger ferry	Roger Skjetne og Mathias Marley
Nora Åsheim	Autonomous ship maneuvering with guaranteed safety	Roger Skjetne og Mathias Marley
Yuxuan Cai	Condition monitoring and fault detection for marine battery energy storage systems	Roger Skjetne, Zhengru Ren og Namireddy Praveen Reddy
Jooyoung Park	User interface for simultaneous supervision of several autonomous ships	Ole Andreas Alsos and Øyvind Smogeli
Sondre Ek	Developing the Gemini simulator	Ole Andreas Alsos and Erik Veitch
Olav Sigmund Buset Vassbotn	Analysis of ship collision risk encounters and COLREGS behaviours using machine learning and AIS data	Tor Arne Johansen, Inger Hagen
Tom Daniel Grande	PSB-MPC Collision Avoidance with Anti-Grounding	Tor Arne Johansen
Kristoffer Nordvik	Dynamic positioning during launch and recovery for an unmanned autonomous ROV supply vessel	Tor Arne Johansen
Simen Krantz Knudsen	Model validation and berthing of an autonomous ferry	Tor Arne Johansen, Håkon Helgesen, Giorgio Kufoalor
Thea Kristine Bergh	ENC-based Collision and Grounding Avoidance System for a Green-Energy Autonomous Surface Vehicle	Tor Arne Johansen, Alberto Dallolio
Dinosshan Thiagarajah	Localization of Ferries using Monocular Camera, IMU, and GNSS during Automated Docking	Håkon Helgesen, Tor Arne Johansen, Trym Håvardsholm
Kjetil Sekse Kristiansen	Contact detection for autonomous boats using machine learning	Håkon Helgesen, Tor Arne Johansen
Thomas Fuglstad	Positioning and Sensor Fusion for Docking of Autonomous Ship	Håkon Helgesen, Tor Arne Johansen
Jakob Løver	Explaining a deep reinforcement learning agent using regression trees	Anastasios Lekkas
Peter Bull Hove	Perception and high-level control for autonomous drone missions	Anastasios Lekkas

Annual Accounts for 2021

FUNDING	AMOUNT
The Research Council	3 611
The Host Institution (NTNU)	5 687
Research Partners*	1 085
Enterprise partners**	6 785
Public partners***	164
Total	**17 332**

COST	AMOUNT
The Host Institution (NTNU)	9 106
Research Partners*	5 687
Enterprise partners**	1 085
Public partners***	164
Equipment	
Total	**17 332**

*Research Partners**

Universitet i Oslo
SINTEF Digital
SINTEF Ocean AS
Institutt for Energiteknikk

*Enterprise Partners***

MacGregor Norway AS
DNV AS
Embron Group AS
GARD
Telia
Maritime Robotics AS
North Sea Container Line
Kongseberg Maritime
Idletechs
Equinor
Massterly
Trondheim Havn
G2 Ocean AS
Grieg Star AS
Torghatten ASA

*Public Partners****

Sjøfartsdirektoratet
Kystverket
Trondheim Kommune

Key Personnel

CENTRE MANAGEMENT AND ADMINISTRATION

Mary Ann Lundteigen	Centre director
Ingrid Wouwer Utne	Centre co-director and WP 4 leader
Trond Johnsen	Centre co-director and WP 6 leader
Elisabeth Strand Vigtel	Administrative coordinator
Steve Harila Løkkeberg	Finance

KEY RESEARCHES	NTNU	MAIN RESEARCH AREA
Edmund Brekke	Dept. of Engineering Cybernetics	Sensor fusion
Tor Arne Johansen	Dept. of Engineering Cybernetics	Automatic control
Mary Ann Lundteigen	Dept. of Engineering Cybernetics	Safety, reliability and automation systems
Adil Rasheed	Dept. of Engineering Cybernetics	Big Data Cybernetics, Hybrid Analysis and Modelling
Thor I. Fossen	Dept. of Engineering Cybernetics	Cyber security, navigation and control of marine craft
Anastasios Lekkas (interim leader WP 1)	Dept. of Engineering Cybernetics	Autonomous systems
Annette Stahl	Dept. of Engineering Cybernetics	Robotic vision
Torbjørn Ekman	Dept. of Electronic Systems	Radio communications, communication theory and signal processing
Ingrid Bouwer Utne	Dept. of Marine Technology	Operational risk in marine and maritime systems
Roger Skjetne	Dept. of Marine Technology	Marine cybernetics
Kjell Olav Skjølsvik	Dept. of Marine Technology	Innovation manager
Egil Eide	Dept. of Electronic Systems	Sensors and autonomous systems
Pierluigi Salvo Rossi	Dept. of Electronic Systems	Signal processing, communication theory, data fusion and machine learing
Kimmo Kansanen	Dept. of Electronic Systems	Signal processing
Ole Andreas Alsos	Dept. of Design	Interaction Design
Thomas Porathe (retired)	Dept. of Design	Human factors and remote control centres
Magne Aarset	Dept. of Ocean Operations and Civil Enginnering	Risk Management/Artificial Intelligent
Runar Ostnes	Dept. of Ocean Operations and Civil Engineering	Nautical science, navigation systems and nautical operations
Ottar L. Osen	Dept. of ICT and Natural Sciences	Cybernetics and Artificial Intelligence

KEY RESEARCHES	UNIVERSITY OF OSLO (UIO)	MAIN RESEARCH AREA
Trond Solvang	UiO, Scandinavian Institute of Maritime Law	Maritime law, torts law, contract law

KEY RESEARCHES	SINTEF	MAIN RESEARCH AREA
Trond Johnsen	SINTEF Ocean	Maritime transport and logistics
Ørnulf Rødseth	SINTEF Ocean	Maritime digitalization, autonomous control system design
Odd Erik Mørkrid	SINTEF Ocean	Maritime logistics and autonomous shipping
Håvard Nordahl	SINTEF Ocean	Energy and transport
Espen Tangstad	SINTEF Ocean	Autonomous control system design
Dag Atle Nesheim	SINTEF Ocean	Energy and transport
Lars Andreas Lien Wennersberg	SINTEF Ocean	Methods for design, analysis and approval of merchant autonomous ship systems
Sture Holmstrøm	SINTEF Digital	Safety, risk assessment
Esten Ingar Grøtli	SINTEF Digital	Localization, estimation, path planning
Erlend Solbakk Harbitz	SINTEF Digital	Tracking, localization, marine control systems
Marialena Vagia	SINTEF Digital	Cargo handling, control systems

KEY RESEARCHES	INSTITUTE FOR ENERGY TECHNOLOGY (IFE)	MAIN RESEARCH AREA
Bjørn Axel Gran	IFE	Risk, safety and security
Stine Strand	IFE	Control room and interaction design
Linda Sofie Lunde-Hanssen	IFE	Control room and interaction design
Stine Aurora Mikkelsplass	IFE	Risk, safety and security