NTNU AMOS
Centre for Autonomous Marine
Operations and Systems

NTNU AMOS
Centre for Autonomous Marine Operations and Systems

Annual Report 2015

Norwegian
Centre of
Excellence

The Research Council of Norway

OUR VISION

To establish a world-leading research centre for autonomous marine operations and systems:
To nourish a lively scientific heart in which fundamental knowledge is created through multidisciplinary theoretical, numerical, and experimental research within the knowledge fields of hydrodynamics, structural mechanics, guidance, navigation, and control. Cutting-edge inter-disciplinary research will provide the necessary bridge to realise high levels of autonomy for ships and ocean structures, unmanned vehicles, and marine operations and to address the challenges associated with greener and safer maritime transport, monitoring and surveillance of the coast and oceans, offshore renewable energy, and oil and gas exploration and production in deep waters and Arctic waters.

Editors: Annika Bremvåg, Thor I. Fossen and Asgeir J. Sørensen

TABLE OF CONTENTS

DIRECTOR'S REPORT – TIME TO INVEST AND HARVEST KNOWLEDGE AND COMPETENCE

NTNU AMOS has completed the third year of operation. It is fair to say that we have become *a centre of gravity* for fundamental education, research and innovation on autonomous marine operations and systems. Currently, close to 80 PhD candidates and 100 MSc students are engaged at NTNU AMOS. The footprint and value of the hundreds of MSc and PhDs that have graduated on the topics of the Centre cannot be overestimated. Fundamental knowledge is developed, and scientific results are published in highly ranked peer reviewed journals and international conference proceedings. National and international cooperation has been vital for the outcome and success.

More than ever, 2015 has reminded us of the effects of globalization and sustainability and of the importance of being willing and capable to drive changes. Norway is facing increasing challenges related to unemployment after years of growth in the offshore energy sector. On the other hand, the seafood industry is at an all-time high activity level.

Norway is one of the world's leading players, hosting a *supercluster* of industries associated with the ocean. The *blue economy*, consisting of the three big industries, *offshore oil and gas, maritime*, and *fisheries and aquaculture* in addition to emerging areas such as *offshore renewable energy, marine mining, tourism* and *marine science*, will for decades be important for the welfare of Norway. This fact underlines the foundation and importance of NTNU AMOS by investing in knowledge and competence and the expectation of society to reap the benefits.

Seen from the point of view of the Centre of Excellence and the University, we have a special responsibility to respond to both long- and short-term challenges and turn them into opportunities and changes. One important role is to develop relevant knowledge and competence and to ensure that the best practices are transferred between the sectors in the blue economy. One aspect of this is to maintain and even strengthen the efforts that will create cost-effective innovations in the oil and gas industry. The challenges related to an increasing cost level have to be met by new technology and methods that are more efficient. Game-changing disruptive innovations are needed. NTNU AMOS is addressing this heavily by combining enabling technology, such as ICT, material technology, and biotechnology, with established marine technology. One highlight of this is the establishment of the company Eelume AS. After years of research on land-based snake robotics in cooperation with SINTEF, NTNU AMOS has, during the last three years, developed prototypes of underwater hyper-redundant flexible robots. In June 2015, the spin-off company Eelume AS was established to continue the commercialization process.

NTNU AMOS is promoting technology and methods that will contribute to a greener world, *the green shift*, by working on a variety of areas, such as energy optimization and the introduction of hybrid power plants, which take advantage of e.g., energy storage devices such as batteries, in combination with optimal driven engines. The potential to reduce fuel consumption and emissions is significant. In addition, offshore renewable energy, in particular offshore wind, is a priority area. In spite of renewable energy, hydrocarbons will be an important contribution to the world's energy supply and mixture for decades. Technology and new methods should contribute to reduce energy consumption and gas emissions.

Norway, with its long coastline and port to the Arctic, has a global responsibility to manage the oceans for the best of mankind. One of the main achievements met together with colleges at the University of Tromsø, The Arctic University of Norway, The University Centre in Svalbard (UNIS), University of Delaware, and The Scottish Association for Marine Science, SAMS is the exploration of the new arctic ocean that is appearing as a consequence of global warming. Fundamental knowledge about ecosystems and marine biology during the polar night is being developed. This is an inter- and multidisciplinary field of research bridging marine science and technology. Advanced sensors on different robotic platforms in the air, on the sea surface and underwater have enabled scientists to reach new levels of ocean research.

It is also with great pleasure and proudness that I recognize that Professor Thor I. Fossen was elevated to *IEEE fellow* for his contribution to modelling and control of marine craft. Fossen has made ground-breaking contributions to the field of marine control systems in several areas, including modelling, estimation and control. He is probably most famous for the development and formulation of the so-called *Fossen control and simulation models*, which characterized the manoeuvring and station keeping of marine craft. In addition, he has developed a wide range of control methods for ships and underwater and aerial vehicles.

I will take this opportunity to thank all colleges, researchers, PhDs and MSc students, partners and collaborators for their efforts in *creating competence, knowledge and innovations for a better world.*
Sincerely

Professor Asgeir J. Sørensen
Director NTNU AMOS

ORGANIZATION, COLLABORATORS, AND FACTS AND FIGURES 2015

NTNU AMOS Board
Members:
Dean Ingvald Strømmen, Chair, NTNU
Dean Geir E. Øien, NTNU
Torbjørn Digernes, NTNU
Oddvar I. Eide, MARINTEK
Kjetil Skaugset, Statoil
Liv A. Hovem, DNV GL

Observers:
Morten Breivik, NTNU
Harald Ellingsen, NTNU
Aage Thunem, SINTEF ICT
Karl Almaas, SINTEF Fisheries & Aquaculture

NTNU AMOS Management
Asgeir J. Sørensen, Director
Thor I. Fossen, Co-director
Sigrid B. Wold, Senior Executive Officer
Annika Bremvåg, Higher Executive Officer

NTNU AMOS Key Scientists
Jørgen Amdahl, Marine Structures
Thor I. Fossen, Guidance, Navigation and Control
Marilena Greco, Hydrodynamics
Tor Arne Johansen, Optimization and Control
Kristin Y. Pettersen, Motion Control
Asgeir J. Sørensen, Marine Control Systems

Senior Scientific Advisers
Odd M. Faltinsen, Hydrodynamics
Torgeir Moan, Marine Structures

Innovation
Eli G. Aursand, NTNU Technology Transfer
Anders Aune, NTNU Technology Transfer

Research Partners
DNV GL, MARINTEK, Dept. of Marine Technology and Dept. of Engineering Cybernetics at NTNU, SINTEF Fisheries & Aquaculture, SINTEF ICT, Statoil

User Panel
Members from research partners, companies and industry

Scientific Advisory Board
Randy Beard, Brigham Young University, USA
Robert F. Beck, University of Michigan, Ann Arbor, USA
Gianluca Antonelli, University of Cassio and Southern Lazio, Italy

National collaborators

NTNU AMOS co-operates with many companies in research and development (R&D), the education of PhD candidates, and the sharing of research infrastructure and joint publications. The national co-operators are organised as associated R&D projects with PhD candidates and postdocs working in teams. The following companies and research institutes are currently co-operating with NTNU AMOS:

- Akvaplan Niva, contact person: Dr Stig Falk-Petersen
- BluEye Robotics AS, contact person: Erik Dyrkoren
- Ecotone AS, contact person: Ivar Erdal
- Eelume AS, contact persons: Professor Kristin Ytterstad Pettersen, Dr Pål Liljebäck
- FMC Technologies, contact person: Dr Tor Berge Gjersvik
- Kongsberg Maritime, contact persons: Dr Nils Albert Jenssen, Bjørn Gjeldstad, Arne Rinnan
- Marine Technologies LLC, contact persons: Jan Mikalsen, Sveinung Tollefsen
- Maritime Robotics AS, contact person: Vegard E. Hovstein
- NORUT, contact person: Dr Rune Storvold
- Geological Survey of Norway (NGU), contact person: Terje Thorsnes
- Norwegian Defence Research Establishment (FFI), contact persons: Nils-J. Størkersen, Stein Grinaker
- Rolls-Royce Marine, contact person: Dr Ivar A. Ihle
- The University Centre in Svalbard (UNIS), contact persons: Professors Geir Johnsen and Jørgen Berge
- The Arctic University of Norway, University of Tromsø - ARCTOS and Mare Incognitum, contact person: Professor Jørgen Berge
- Ulstein Group, contact persons: Dr Tore Ulstein, Dr Per Olav Brett

International collaborators

Co-operation with international universities and research institutes occurs in the form of the two-way exchange of senior researchers and PhD candidates, the sharing of research infrastructure, and joint publications, regulated by a signed agreement. NTNU AMOS researchers are currently co-operating with the following institutions:

- CNR-INSEAN, Italy
- Technical University of Denmark, Denmark
- Eindhoven University of Technology, Netherlands
- Instituto Superior Técnico, Portugal
- Jet Propulsion Laboratory, NASA, USA
- National Academy of Science of Ukraine, Ukraine
- University of California, Berkeley, USA
- University of California, Santa Barbara, USA
- University of Delaware, USA
- University of Linköping, Sweden
- University of Newcastle, Australia
- University of Porto, Portugal
- Woods Hole Oceanographic Institution, USA
- University of Zagreb, Croatia
- University of Cassino and Southern Lazio, Italy

Facts and Figures 2015

Personnel at the end of 2015

- 10 adjunct/adjunct associate profs.
- 13 affiliated scientists
- 4 postdocs
- 9 graduated PhD candidates
- 63 graduated MSc students

Personnel during 2015

- 6 key scientists (profs.)
- 2 scientific advisers
- 81 PhD candidates
- 5 visiting profs./researchers
- 2 administrative staff
- 2 management
- 2 technical staff

Revenues (amount in NOK 1000)

- Income: 66 669 NOK
- Costs: 70 109 NOK
- Year end allocation: -3 440 NOK

Publications

- 3 book chapters
- 95 refereed journal articles
- 151 refereed conference papers
- 10 international keynote lectures

Dissemination

- 24 guest lectures have been delivered at NTNU AMOS by national and international visitors.
- 49 popular science publications and presentations have been delivered in newspapers, TV, radio, museums, online and in conferences.

Innovation

- 2 company start-ups
- 3 patents

PRESENTATION OF NEW AFFILIATED SCIENTISTS

Arne Fredheim

Adjunct Professor, Department of Marine Technology, NTNU

Adjunct professor Arne Fredheim received his Master's degree in Marine Technology in 1992 and his PhD degree in Marine Hydrodynamics in 2005 from the Department of Marine technology, Norwegian University of Science and Technology (NTNU). He has been employed by SINTEF Fisheries and Aquaculture since 1999. He has held several research and management positions within the research institute and is presently Research Director for the Department of Aquaculture Technology. He was Centre Director of the Centre for Research-Based Innovation in Aquaculture Technology (CREATE) from 2007 to 2015.

His recent research has investigated topics related to technology for marine aquaculture, offshore aquaculture, structural and hydrodynamic analysis and assessment of floating fish farms and design criteria to prevent the escape of fish from floating aquaculture installations.

He is a leading expert of the Future Prospects of Marine Aquaculture under the OECD project "The Future of the Ocean Economy", has served as a conveyor for the work group on aquaculture technology under the ISO/TC 234 Fisheries and Aquaculture Standards, is a former board member of the European Aquaculture Society (2010 – 2014) and the French Norwegian Foundation (Research), and is a former member of the Norwegian Aquaculture Escape Commission.

Martin Føre

Adjunct Associate Professor, Department of Engineering Cybernetics, NTNU

Adjunct associate professor Martin Føre received his PhD degree in Engineering Cybernetics at NTNU in 2011, with a thesis focused on estimating and observing fish behaviour using individual-based modelling and observation technologies. After his dissertation, he started a postdoctoral fellowship at NTNU, during which he worked further on the models developed in his PhD.

While working as a PhD and postdoctoral fellow at NTNU, he held a part-time position at SINTEF Fisheries and Aquaculture, where he is today employed as a Research Scientist. His research activities at SINTEF are primarily within mathematical modelling and the development and use of technology to monitor fish in sea-cages, and his role in NTNU AMOS also focuses on these topics. He is presently associated with several research projects at SINTEF that will be relevant for his work at NTNU AMOS, including the EU-project AQUAEXCEL2020, and the Centre for Research-Based Innovation EXPOSED.

Zhen Gao

Professor, Department of Marine Technology, NTNU

Prof. Zhen Gao obtained his PhD degree at NTNU in 2008 and then worked as a postdoc and a researcher at CeSOS from 2008 to 2015. Currently, he is a professor of marine structures in the Department of Marine Technology, and his professorship is financed by DNV GL. His main research works are related to offshore renewable energy, with focuses on the design, modelling and analysis of bottom-fixed and floating wind turbines, and marine operations related to installation and maintenance of offshore wind turbines. He has published more than 100 peer-reviewed journal and conference papers. He has participated in several EU projects and in one national research centre project on offshore wind. He is the chair of the Specialist Committee V.4 Offshore Renewable Energy in ISSC (2012-2018).

Vahid Hassani

Adjunct Associate Professor, Department of Marine Technology, NTNU

Adjunct associate professor Vahid Hassani received his Master of Science degree (hons.) in 2005, with a final thesis on "Control under Communication Constraints". In 2006, Vahid joined the research group of the legendary Profs. Michael Athans and Antonio Pascoal, where he was engaged in the research and development of novel methodologies in robust adaptive control using multi-model techniques.

He received his PhD in 2012 and joined the Norwegian Marine Technology Research Institute (MARINTEK) as a research scientist in 2013, where he has been conducting research in many fields of marine control, including dynamic positioning, the design of ride control systems for high speed vessels and surface effect ships, and the virtual prototyping of marine systems and operations. Moreover, he has been involved in the development of new methodologies for cyber-physical hybrid model testing at MARINTEK.

In 2014, Vahid undertook a 50% postdoctoral research fellowship at NTNU AMOS. In 2015, he became an adjunct associate professor in the Department of Marine Technology, NTNU, where he has been active in teaching and supervising master and PhD candidates. Vahid's main research interests lie in optimal control, numerical optimization, and robust adaptive control (and estimation) with applications to fault detection, parameter estimation, and autonomous systems. He is currently devising several new national and international research projects on remote and autonomous cargo vessels, sea state estimation, and emission control in marine systems.

In parallel to his research and teaching duties, Vahid is an editor, technical program chair, and vice-chair of the national organizing committee of the 10th IFAC Conference on Control Applications in Marine Systems (CAMS 2016) to be held in Trondheim, Norway, 13-16 September 2016.

Trygve Kristiansen

Professor, Department of Marine Technology, NTNU

Trygve Kristiansen earned his MSc degree in Applied Mathematics from NTNU in 2002. He was employed at MARINTEK during 2002 – 2015, where he worked on different topics within offshore hydrodynamics, including wave run-up on platforms, vortex-induced vibrations, riser galloping, ship roll, moon-pool resonance, shallow water wave loads and responses of offshore wind turbines and aquaculture structures in waves and currents. He was a member of an ITTC committee on wave run-up and VIV in 2013.

Meanwhile, he earned his PhD degree in marine hydrodynamics from NTNU in 2009, and held a three-year postdoc position during 2010-2012, both at the Centre for Ships and Offshore Structures (CeSOS) at NTNU. His PhD and postdoc research topics mainly included moonpool resonance and aquaculture structures. He employed both experimental, numerical and theoretical research methods. The work on moonpools has led to new, fast and robust computational methods for *marine resonance* problems, such as moonpool ship-by-ship situations and ship roll. MARINTEK is presently developing a commercial code called the Potential Viscous code (PVC3D) based on this work. He developed new rational hydrodynamic load models for fish farm nets that are useful for the industry.

Since June 2015, he has held a professorship in "Marine Operations, with a focus on hydrodynamics" in the Department of Marine Technology at NTNU. Statoil is financing the first five years of the position. He will focus on developing useful knowledge and technology for different hydrodynamic aspects of marine operations, using both experimental, numerical and theoretical research methods.

BOARD OF DIRECTORS

Figure 1: *From the left: Liv A. Hovem (Director of Operations, DNV GL), Torbjørn Digernes (Rector staff, NTNU), Geir Egil Øien (Dean, Faculty of Information Technology, Mathematics and Electrical Engineering, NTNU), Asgeir J. Sørensen (Director, NTNU AMOS), Ingvald Strømmen (Chair, Dean, Faculty of Engineering Science and Technology, NTNU), Oddvar I. Eide (President, MARINTEK), and Kjetil Skaugset (Chief Researcher, STATOIL).*

The Board is very satisfied with the activities undertaken at NTNU AMOS during 2015. The Centre and its staff show impressive momentum and are well on track to reach the Centre's ambitious goals. NTNU AMOS is central in fulfilling the vision of NTNU's strategic research area—Oceans. NTNU AMOS currently employs 6 key scientists, 10 adjunct professors, 4 postdoctoral researchers and 81 PhD candidates. In addition, 13 scientists are affiliated with the Centre. These are remarkable numbers after three years of operation, and recruitment has been excellent. The Board met twice in 2015 to review progress, consider management issues, and offer advice on strategic directions for the Centre.

The Centre has succeeded beyond expectations in attracting funding in addition to that contributed by the Research Council of Norway and NTNU. By the end of 2015, twelve externally funded research projects were associated with the NTNU AMOS portfolio. Eight of these projects are partially funded by industrial partners, while three projects are highly competitive individual projects of high scientific quality funded by the Research Council of Norway under the FRINATEK and FRITEK programmes. In 2015, professor and key scientist Tor Arne Johansen was granted a fellowship from the MarineUAS research project, which is a comprehensive Marie Curie Innovative Training Network (ITN) funded by the European Commission. MarineUAS further strengthens the Centre's international cooperation and will contribute to training 15 European PhD candidates in Norway, Portugal, Spain, and Sweden. The international collaborators are important partners for students and researchers and align with our goal of international cooperation.

The Board also wishes to note the Centre's School of Innovation, which is a pilot programme in cooperation with the NTNU Technology Transfer. All AMOS PhD candidates experience innovation training as a part of their PhD programmes. By the end of the year, NTNU AMOS contributed to the establishment of three spin-off companies: *Norwegian Subsea, Eelume,* and *BlueEye Robotics*. The strategic goal of NTNU AMOS, to contribute to the establishment of 10 companies within 10 years of operation, seems quite realistic.

The Board is very satisfied with NTNU AMOS publication and dissemination. International publication was further strengthened by the publications of 95 journal papers and 151 conference papers in 2015. This is impressive publication growth, and the increase in high-quality journal publications is particularly noted. The Centre had graduated 9 PhD candidates by the end of 2015.

Finally, the Board looks forward to an exciting and productive year in 2016, with an increasing number of high-quality publications, excellent PhD candidates, and new spin-off companies. The Board is pleased that the NTNU AMOS School of Innovation is evolving into the Ocean School of Innovation, involving the Centres for Research-Based Innovation (SFIs): SAMCOT, MOVE, EXPOSED and Smart Maritime.

The Board's endorsement of the annual report

The main responsibility of the Board of Directors is to ensure that NTNU AMOS achieves its goals within the resources available and within the research plan established by the Centre. As part of their duties, the Board members have discussed and endorsed this annual report.

Oddvar Inge Eide

Member of NTNU AMOS' Board of Directors
President of MARINTEK

My background story

I grew up on a small island on the west coast of Norway. My father was a sea captain, so my interest in ships and ocean structures came naturally from an early age. I earned my BSc degree in Naval Architecture at Bergen Technical College in 1972 and continued my studies at NTNU, earning my MSc in Marine Structures in 1976 and my PhD in Marine Engineering in 1983.

In 1985, I joined SINTEF Structural Engineering. I was appointed Research Manager for Marine structures in 1987 and Research Director for SINTEF Structural Engineering in 1995. My main areas of technical competence are related to the design and integrity assessment of offshore structures, risers and umbilicals. I was central in the development of testing facilities for flexible risers and umbilicals, and I have conducted more than 30 full-scale and midscale tests of these types of structures for design verification and safe operation.

In 1999, SINTEF Structural Engineering merged with MARINTEK. From my position as Research Director, I was appointed President of MARINTEK in 2009.

Developing the oceans

The oceans contain enormous resources for mankind—resources that become even more important as the world's population increases and we experience a shortage of land-based resources. The challenge is to harvest these resources in a sustainable manner so that they also can be maintained for new generations. This requires knowledge and technology. New ocean industries such as renewable ocean energy, deepsea mining and a portfolio of bio marine industries are evolving, as are operations in Arctic waters. Throughout the years, we have been developing knowledge and technologies for the marine, maritime and offshore oil and gas industries. This competence is invaluable as we now develop and enter new ocean industries. However, new technologies such as autonomous systems are emerging, opening new possibilities when developing ocean industries for future generations. The development of autonomous systems for the ocean industries is the main target of NTNU AMOS. In my opinion, the activities of the Centre are crucial for developing new knowledge of great importance for the ocean industries of tomorrow. I take great interest in watching these developments from my position as a member of NTNU AMOS' Board of Directors.

MARINTEK – research partner in NTNU AMOS

MARINTEK is co-located with the NTNU Department of Marine Technology and NTNU AMOS at the Marine Technology Centre. All parties in the Marine Technology Centre are cooperating closely towards the further development of ocean industries and the ocean space. MARINTEK is a research partner in NTNU AMOS, as we were in the former Centre of Excellence CeSOS. We consider our participation in the Centre of Excellence to be of great importance to our own activities, allowing us to combine the more strategic and fundamental research activities in NTNU AMOS with our own applied research, to the mutual benefit of both parties and the society. This type of collaboration describes the "inner beauty" of the logic of the activities at the Marine Technology Centre.

PhD and postdoc candidates are important assets at NTNU AMOS. For years, MARINTEK has had the privilege to recruit highly qualified personnel from CeSOS. We expect this to continue with NTNU AMOS. Recruiting young talent is very important to us because we must offer the best competence to demanding clients in the applied research market.

Towards Ocean Space Centre

Together with NTNU, we are developing the next-generation research centre within ocean space technologies. The Ocean Space Centre will be a "Centre of Gravity", which will operate in alliances with national and international competence clusters to cover the multidisciplinary needs to meet all challenges in the entire ocean space. It will be equipped with research facilities with content and a size capable of delivering state-of-the-art research and development well beyond 2050. Our cooperation with NTNU AMOS is important to achieve the overall goals and ambitions in the Ocean Space Centre because they contribute novel and valuable knowledge in this development.

Geir Egil Øien

Member of NTNU AMOS' Board of Directors
Dean of the Faculty of Information Technology, Mathematics, and Electrical Engineering (IME) at NTNU

Who am I?

I was born in Trondheim in 1965. I received my MSc in Electronics in 1989 and my PhD in Telecommunications in 1993, both from the Norwegian Institute of Technology (NTH). Since 2001, I have held a full professorship in Information Theory at NTNU. My research interests are in information and communication theory, signal processing, and wireless communications.

Since 2009, I have served as Dean of the Faculty of Information Technology, Mathematics, and Electrical Engineering (IME) at NTNU. IME is the largest provider of higher education in information and communication technologies, mathematical sciences and electrical engineering in Norway, producing approximately 550 master students and 55 PhD graduates per year. Our research is on a high international level, and we participate in several national excellence centres. EU funding is an increasingly important part of IME's project portfolio, and the faculty has a proud history of innovation and entrepreneurship.

My contributions to the NTNU AMOS board

NTNU AMOS is a spearhead of excellent research for NTNU and for both participating faculties. As dean of one of these two faculties, I am committed to the centre's development, and I see it as an important task to contribute to enabling the centre to reach its many important goals. Indeed, it is both inspiring and exciting for me to be able to follow and give advice to NTNU AMOS as a member of the board. It is also a great learning experience for someone whose academic background lies somewhat outside the centre's main scope.

The board has an important formal control and governance function, but it is good to observe that administrative issues in NTNU AMOS are handled so smoothly and professionally that the board's main role in practice is to be a strategic discussion partner. I contribute to the discussion from the viewpoint of ICT, mathematics and electrical engineering, to ensure that the potential of these enabling disciplines and technologies is fully exploited towards the success of NTNU AMOS.

The IME Faculty and NTNU AMOS

IME and the host Faculty of Engineering Science and Technology (IVT) are equal partners in NTNU AMOS. The Centre's co-director and half the core team of the Centre's senior researchers come from IME's Department of Engineering Cybernetics, and the budget and volume of research activities are roughly equally divided between IME and IVT. As such, NTNU AMOS is of crucial strategic importance for IME owing to the volume, scientific quality, societal relevance, impact, and cross-disciplinary potential of the centre's activities, both in research and education.

Ideas for the future

There is no doubt that engineering cybernetics is a crucial enabling technology for NTNU AMOS. However, I strongly believe that several other IME knowledge fields can also have something to offer the Centre and would benefit from closer collaboration with it. Indeed, centre director Asgeir J. Sørensen has stressed the importance of integrating knowledge from all IME departments to ensure truly ground-breaking results in NTNU AMOS.

For example, Big Data analytics, sensor technology, communication networks, radio systems, machine learning, mathematical modelling and optimization, marine acoustics, and marine and offshore power systems are all strong IME research fields that I believe could contribute something within NTNU AMOS. I hope to see even more collaborations open up between the Centre and IME in the future!

RESEARCH HIGHLIGHTS

The research at NTNU AMOS is divided into two research areas which are described below.

Research area 1: Unmanned Vehicles and Robots
The importance of autonomous systems for monitoring and data collection is increasing. We use autonomous vehicles in many marine operations to improve operational safety and collect data for various applications. This includes autonomous underwater vehicles (AUVs), unmanned surface vehicles (USVs) and unmanned aerial vehicles (UAVs), which can operate alone or as networked vehicles. Each vehicle has a dedicated payload system for autonomous guidance and navigation and mission-specific sensors for perception and data collection. In addition to the unmanned vehicles, NTNU AMOS researchers work on robotic tools and intervention systems. The most exotic ones are underwater snake robots, which change how offshore inspection, maintenance and repair are performed. Snake robots have much better manoeuvrability compared with conventional remotely operated vehicle (ROV) systems.

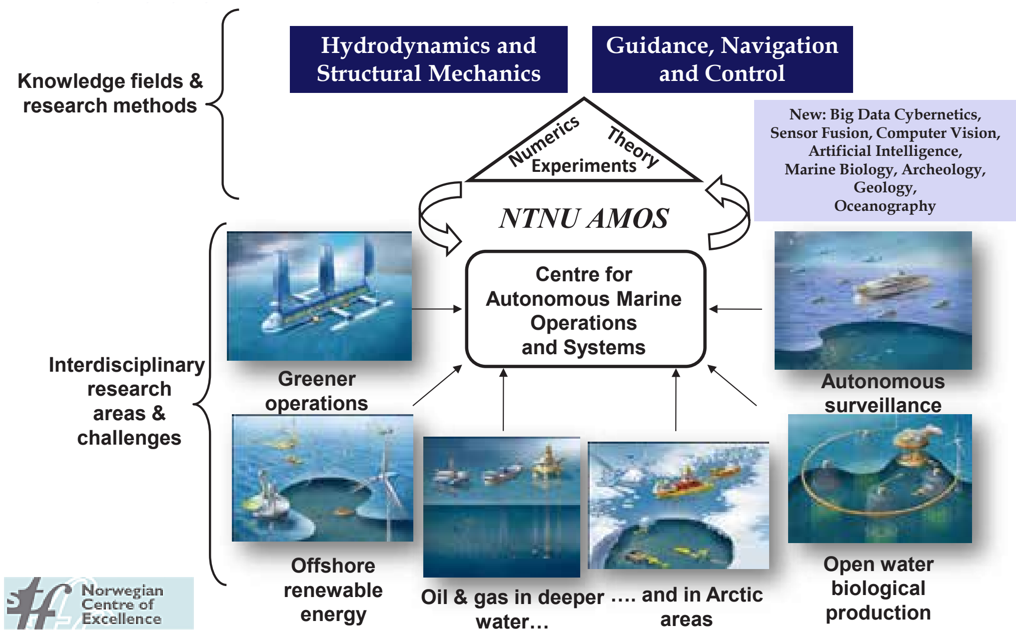
Research area 2: Safer, smarter and greener marine operations
Safer, smarter and greener marine operations are both a vision and research area for NTNU AMOS.

The research covers hydrodynamics, structural mechanics, estimation, control and optimization for offshore renewable wind energy harvesting, intelligent aquaculture structures, hybrid power plants on ships and rigs, and marine operations in deep water and in the arctic, in addition to accidents and abnormal events on ships and offshore structures.

Some key aspects of research driven by hydrodynamics as an input for marine operations as well as design of marine structures and control systems are:

- hydrodynamic loadings on fish farms in presence of fish
- moonpool operations and how moonpool dynamics affect ship motions
- calculation of involuntary and voluntary speed-loss predictions and its effects on power increase and corresponding fuel consumption and CO_2 emissions
- sloshing in LNG tanks
- oil spills and hydro-elastic interaction in case of underwater explosions

Next step in research, education and innovation



RESEARCH AREA: UNMANNED VEHICLES AND ROBOTS

Autonomous marine robotic systems

Supervisor: Professor Kristin Y. Pettersen
PhD candidates: Jørgen Sverdrup-Thygeson, Martin Syre Wiig, Anna Kohl, Albert Sans Muntadas, Claudio Paliotta, Dennis J.W. Belleter, Signe Moe, Eleni Kelasidi, Filippo Sanfilippo, Ehsan Rezapour

The project considers autonomous marine robotic systems, including marine multi-agent systems, underwater snake robots, ROV control systems, control of marine cranes, and autonomous docking of marine vehicles.

Control of systems consisting of multiple agents has been a topic of active research in the control community in recent years. The motivation for using multi-agent systems is that they can perform tasks more time efficiently and cost effectively than a single, often more complex, vehicle. Moreover, the financial and operational consequences of vehicle loss in inaccessible environments, such as deep sea or under ice, are less severe. Coordinated path following for multi-agent systems is valuable, especially for information gathering tasks, in which the formations can be used to simultaneously cover a larger area than single vehicles would.

Many research efforts within multi-agent systems have been concentrated on solving the consensus problem and the flocking or rendezvous problem. The coordinated path-following problem for under-actuated robotic systems, with or without disturbances, has received significantly less attention but is a problem often occurring in practice. Furthermore, the effects of environmental disturbances, particularly ocean currents, must be considered, which has been performed only under the assumption of full actuation in previous works. In this project, we have developed a control system for path following for formations of underactuated marine vehicles under the influence of ocean currents. In particular, we have developed a control system for formations of ASVs and AUVs—i.e., both in 2D and 3D—considering both the underactuation and constant ocean currents of unknown magnitude and direction. The main challenge here is to compensate for the ocean current disturbance acting in the sway (and heave) directions in which there is no actuation. Using a combination of Lyapunov theory and cascaded systems theory, we prove that the resulting system is uniformly globally asymptotically stable, thus guaranteeing that all states, both kinematic and dynamic, will converge to their desired values. The theoretical results have been successfully validated through full-scale experiments.

Underwater snake robots offer many interesting capabilities for underwater operations. The long and slender structure of such robots provide superior capabilities for access through narrow openings and within confined areas. This is interesting for inspection and monitoring operations within the subsea oil and gas industry, aquaculture and marine archaeology. In addition, underwater snake robots can provide both inspection and intervention capabilities and are thus interesting candidates for next-generation inspection and intervention AUVs. Furthermore, bioinspired locomotion through oscillatory gaits, such as lateral undulation and eel-like motion, is interesting from an energy efficiency point of view. Increasing the motion efficiency in terms of the achieved forward speed by improving the method of propulsion is a key issue for underwater robots. Moreover, energy efficiency is one of the main challenges for long-term autonomy of these systems. In the project, we consider both of these aspects of efficiency. We have analysed and experimentally investigated the fundamental properties of the velocity and the power consumption of underwater snake robots. In particular, we have investigated the relationship between the parameters of the most common motion gait patterns, which is lateral undulation and eel-like motion, and the forward velocity and energy consumption. The analysis shows a direct relationship among the amplitude, frequency and phase shift of the gait pattern and the forward velocity and power consumption. Both simulations

Figure 2: *The underwater snake robot Mamba developed at NTNU to support the research on both ground and underwater snake robot locomotion. Markers are attached to the tail of the robot for position measurements.*

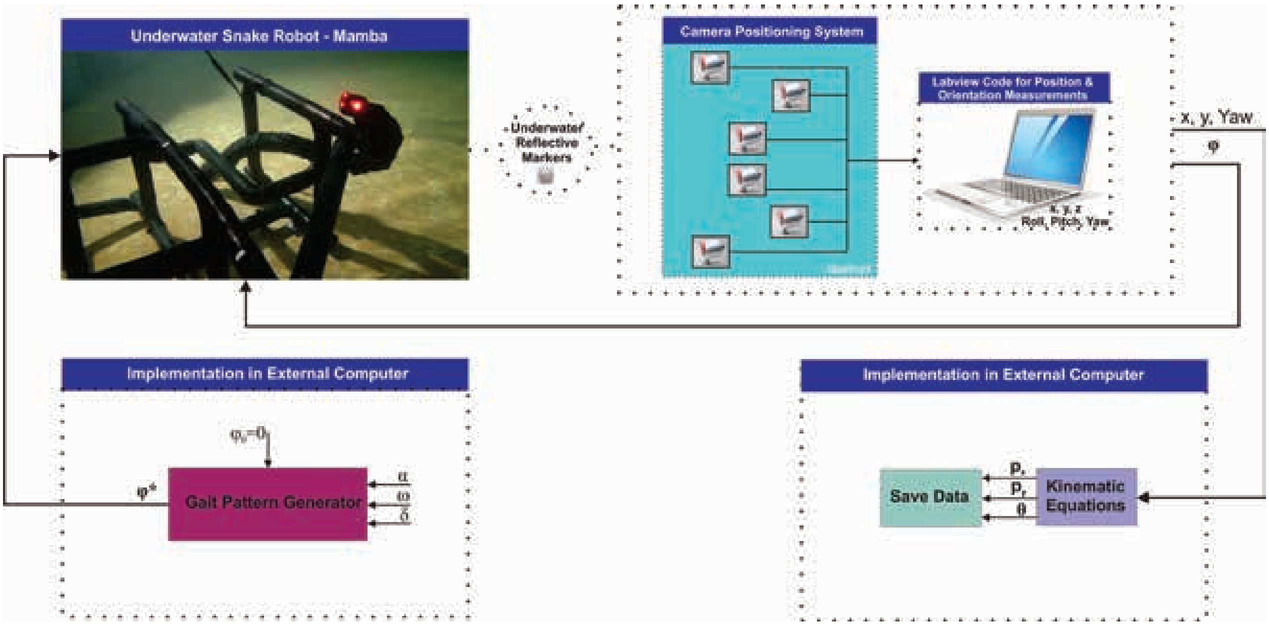


Figure 3: *Illustration of the experimental process adopted in the experiments with the underwater snake robot Mamba.*

and experiments are performed to validate the analysis, and both simulation and experimental results are seen to support the theoretical findings.

Related publications:

- **Fernandes, Daniel de Almeida; Sørensen, Asgeir Johan; Pettersen, Kristin Ytterstad; Donha, Decio C.** Output feedback motion control system for observation class ROVs based on a high-gain state observer: Theoretical and experimental results. Control Engineering Practice 2015 ;Volume 39. p. 90-102
- **Caharija, Walter; Pettersen, Kristin Ytterstad; Bibuli, M.; Calado, P.; Zereik, E.; Braga, J.; Gravdahl, Jan Tommy; Sørensen, Asgeir J.; Milovanovic, M.; Bruzzone, G.** Integral Line-of-Sight Guidance and Control of Underactuated Marine Vehicles: Theory, Simulations and Experiments. Accepted for publication in IEEE Transactions on Control Systems Technology
- **Fossen, Thor I.; Pettersen, Kristin Ytterstad; Galeazzi, Roberto.** Line-of-Sight Path Following for Dubins Paths with Adaptive Sideslip Compensation of Drift Forces. IEEE Transactions on Control Systems Technology 2015 ;Volume 23.(2) p. 820-827
- **Kelasidi, Eleni; Liljebäck, Pål; Pettersen, Kristin Ytterstad; Gravdahl, Jan Tommy.** Experimental investigation of efficient locomotion of underwater snake robots for lateral undulation and eel-like motion patterns. Robotics and Biomimetics 2015 ;Volume 2.(8)
- **Kelasidi, Eleni; Liljebäck, Pål; Pettersen, Kristin Ytterstad; Gravdahl, Jan Tommy.** Biologically Inspired Swimming Snake Robots: Modeling, Control and Experimental Investigation. Accepted for publication in IEEE Robotics and Automation Magazine
- **Mohammadi, Alireza; Rezapour, Ehsan; Maggiore, Manfredi; Pettersen, Kristin Ytterstad.** Maneuvering Control of Planar Snake Robots Using Virtual Holonomic Constraints. Accepted for publication in IEEE Transactions on Control Systems Technology
- **Pettersen, Kristin Ytterstad.** Underactuated Marine Control Systems. I: Encyclopedia of Systems and Control. Springer 2014 ISBN 978-1-4471-5102-9.
- **Sanfilippo, Filippo; Hatledal, Lars Ivar; Styve, A.; Pettersen, Kristin Ytterstad; Zhang, Houxiang.** Integrated Flexible Maritime Crane Architecture for the Offshore Simulation Centre AS (OSC). Accepted for publication in IEEE Journal of Oceanic Engineering
- **Sanfilippo, Filippo; Hatledal, Lars Ivar; Zhang, Houxiang; Fago, Massimiliano; Pettersen, Kristin Ytterstad.** Controlling Kuka Industrial Robots : Flexible Communication Interface JOpenShowVar. IEEE robotics & automation magazine 2015 ;Volume 22.(4) p. 96-109

RESEARCH AREA: UNMANNED VEHICLES AND ROBOTS

Icing protection for small unmanned aircraft

Supervisor: Professor Tor Arne Johansen
PhD candidate: Kim Lynge Sørensen

The research is focused on the development of an intelligent icing protection system (IPS) for small unmanned aerial vehicles (UAVs). The primary focus is on the development of an autonomous anti-icing and de-icing system for exposed aircraft surfaces, such as the leading edge of aircraft wings. The system is based on a laminated resistive thermal source comprising a carbon nanomaterial layer. The composition includes a liquid carrier that facilitates the application of the composition to the substrate surface. Energy (electricity supplied to the thermal source) control is based on thermodynamic theory, linear control theory, nonlinear estimation theory, and fault diagnosis, applied in a novel framework. Research has primarily been conducted at the Norwegian University of Science and Technology, Trondheim, Norway and secondary at NASA-Ames Research Center, Moffet Airfield, Mountain View, California, USA.

The research presented here for 2015 was initiated with the validation of a first version prototype IPS used as a proof-of-concept agent. The scope was to develop an inexpensive and lightweight solution comprising off-the-shelf technologies and control engineering tools in a novel framework. As such, lightweight, off-the-shelf, easy-to-apply, and robust equipment (owing to weight restrictions of UAVs and harsh weather conditions) were all emphasized during the design phase. Figure 4 displays the integration of the thermal source onto an aircraft airfoil, and Figure 5 shows the schematic diagram of the developed IPS.

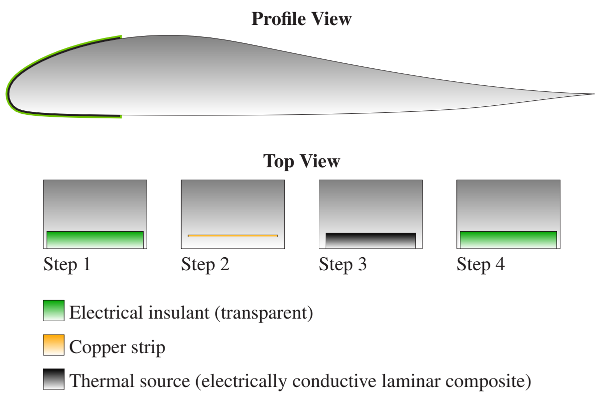


Figure 4: *Thermal source integration (Dragoneye platform airfoil).*

Other research topics include investigations into icing detection and a thermodynamic analysis of an active IPS.

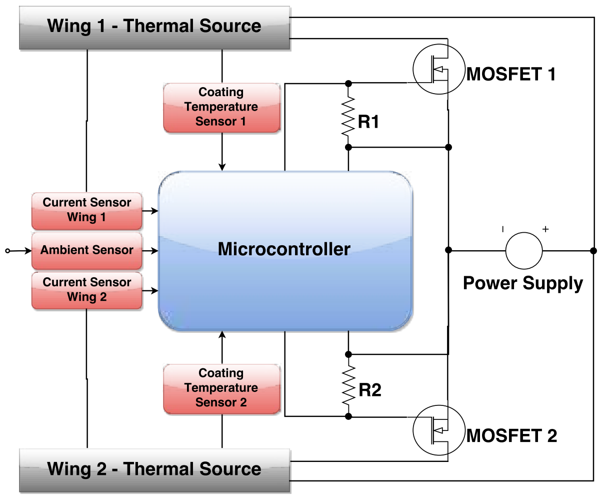


Figure 5: *IPS schematic diagram.*

Icing detection conformed to a fault diagnosis framework, leading to the development of a model-based icing detection algorithm, where icing on the leading edge of aircraft wings was modelled as a structural fault detected by applying a statistical change detection methodology to changes in aerodynamic forces: Figure 6 displays two signals and their respective signal distributions. The signals are based on the difference between aerodynamic parameters for nominal operations, or non-icing operations (faultless), and operations where icing is forming on the leading edge of the aircraft wing (faulty).

To conduct investigations into optimizing power consumption, research into the thermodynamic responses of an active IPS has been initiated. The objective is to study the thermal flow occurring while operating the aforementioned IPS, integrated onto small UAVs. The study encompasses forced convection, transient conduction, and thermal radiation, which are combined to produce an estimate of the heat flow induced and, consequently, the power dissipated when activating the IPS.

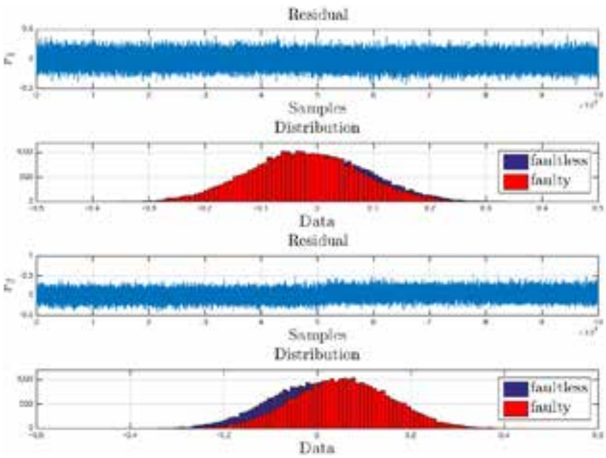


Figure 6: *Residual signals and distributions, with and without icing forming on the leading edge of an aircraft wing.*

Figure 7 display the temperature profile of an X8 platform airfoil, with the IPS thermal source laminated to its leading edge, inserted into a virtual icing wind tunnel, and visualizing the thermodynamic response when activating the IPS. Note that the temperatures in the colour graph are in unit Kelvin.

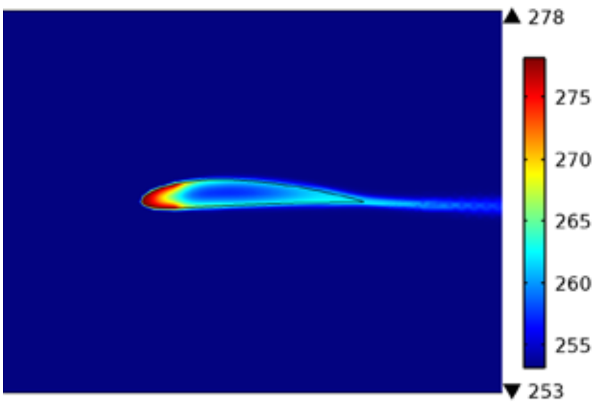


Figure 7: *Thermodynamic response when activating IPS thermal source (X8 platform airfoil).*

In collaboration with NASA Ames Research Center and NOAA, various IPS tests have been conducted. These include test flights in Anchorage, Alaska, in April; tests on the US coast guard icebreaker Healy in the Arctic this summer; and flight tests at Svalbard in September 2015 (see Figure 8). Further test flights are scheduled with NOAA in Antarctica this winter and with the University of Alaska Fairbanks in Alaska, March 2016.

Figure 8: *X8 IPS operations at Svalbard, September 2015.*

Media coverage:

- Inside unmanned systems (journal), New Technologies Aid Arctic Operations, 1 November 2015: http://insideunmannedsystems.com/new-technologies-aid-arctic

Related publications:

- **Sørensen, Kim Lynge; Strand Helland, Andreas; Johansen, Tor Arne**. Carbon Nanomaterial-Based Wing Temperature Control System for In-Flight Anti-Icing and De-Icing of Unmanned Aerial Vehicles. IEEE Aerospace Conference. Proceedings 2015 ;Volume 2015-June
- **Sørensen, Kim Lynge; Blanke, Mogens; Johansen, Tor Arne**. Diagnosis of Wing Icing Through Lift and Drag Coefficient Change Detection for Small Unmanned Aircraft. IFAC-PapersOnLine 2015 ;Volume 48.(21) p. 732-739
- **Sørensen, Kim Lynge; Johansen, Tor Arne**. Thermodynamics of a Carbon Nano-Materials Based Icing Protection System for Unmanned Aerial Vehicles. Accepted to the IEEE Aerospace Conference 2016; 2016-03-05 - 2016-03-12

RESEARCH AREA: UNMANNED VEHICLES AND ROBOTS

Non-linear observers for GNSS- and camera-aided inertial navigation

Supervisors: Professors Thor I. Fossen and Tor Arne Johansen
PhD candidates: Lorenzo Fusini, Håkon H. Helgesen

When operating unmanned aerial vehicles (UAVs) in uncertain and harsh environments, robust navigation is crucial for safe operation and recovery of the vehicle. Conventional flight autopilots use inertial navigation systems (INS) aided by GNSS to compute the position, velocity and attitude (PVA) of the vehicle. The attitude of the vehicle is usually computed by sensing the gravitation vector and using this information together with magnetic field and GNSS course-over-ground (COG) measurements. For autonomous vehicles, it is important to have redundant information if some of the sensors fail to recover the vehicle and avoid accidents. NTNU AMOS researchers have developed nonlinear observers for sensor fusion, which combine optical flow camera measurements with inertial sensors, GNSS and magnetic field measurements. Such systems will be an important step towards the design of fully autonomous vehicles.

Camera-based navigation is important to achieve robust autonomy. Optical flow (OF) is the pattern of apparent motion of objects, surfaces, and edges (features) in a visual scene caused by the relative motion observed by a camera and the scene. Sequences of ordered images allow the estimation of motion as either instantaneous image velocities or discrete image displacements.

Fusini et al. (2014, 2015) developed a vision-aided nonlinear observer under the assumption of flat terrain. The OF estimates the body-fixed relative velocity vector of the UAV, and this is used as an additional measurement in the attitude observer (Grip et al. 2015). The sensor suite consists of an inertial measurement unit (IMU), a GNSS receiver, a video camera, an altimeter, and an inclinometer. The camera and machine vision systems can track features from the environment and calculate the OF. These data and measurements from other sensors are fed to the observer, and the origin of the estimation error is proved to be uniformly semiglobally exponentially stable (USGES).

More recently, the flat terrain assumption has been removed by using epipolar coordinates (Hosen et al. 2016). Epipolar geometry is the geometry of stereo vision. When two cameras view a 3-D scene from two distinct positions, there are a number of geometric relations between the 3D points and their projections onto the 2-D images that lead to constraints between the image points. A benefit of these constraints is that they are independent of the structure being depicted. This implies that we can find the normalized velocity without measuring the distance to the ground without assuming flat terrain. This has been exploited to derive a new nonlinear attitude observer. The equilibrium point of the estimation error is exponentially stable under the assumption that the gyro bias error is known. Exponential stability is important for systems that are exposed to environmental disturbances and uncertain initialisation because it guarantees strong convergence and robustness properties.

Both observers (Fusini et. al., 2014, 2015 and Hosen et al., 2016) have been implemented and tested experimentally onboard the Penguin fixed-wing UAV (see Figures 9–11). The performance of the observers is compatible with the extended Kalman filter (EKF). The main difference of the two nonlinear observers is the flat terrain assump-

Figure 9: *The flight team at Eggemoen Aviation and Technology Park, Norway.*

tion, which degrades the performance of the Fusini et al. (2014, 2015) nonlinear observer when violating the terrain assumption. The Hosen et al. (2016) nonlinear observer shows excellent performance for uneven terrain.

Related publications:

- **Fusini, Lorenzo; Fossen, Thor I.; Johansen, Tor Arne.** A Uniformly Semi-globally Exponentially Stable Non-linear Observer for GNSS- and Camera-Aided Inertial Navigation. *Mediterranean Conference on Control and Automation* 2014 p. 1031-1036
- **Fusini, Lorenzo; Hosen, Jesper; Helgesen, Håkon Hagen; Johansen, Tor Arne; Fossen, Thor I**. Experimental Validation of a Uniformly Semi-globally Exponentially Stable Non-linear Observer for GNSS- and Camera-aided Inertial Navigation for Fixed-wing UAVs. I: *2015 International Conference on Unmanned Aircraft Systems (ICUAS)*. IEEE conference proceedings 2015 ISBN 978-1-4799-6009-5. p. 851-860
- **Grip, Håvard Fjær; Fossen, Thor I.; Johansen, Tor Arne; Saberi**, Ali. Globally Exponentially Stable Attitude and Gyro Bias Estimation with Application to GNSS/INS Integration. *Automatica* 2014 ;Volume 51. p. 158-166
- **Hosen, Jesper; Helgesen, Håkon Hagen; Fusini, Lorenzo; Fossen, Thor I.; Johansen, Tor Arne**. Vision-aided Nonlinear Observer for Fixed-wing Unmanned Aerial Vehicle Navigation. Journal of Guidance, Control, and Dynamics, 2016, to appear.

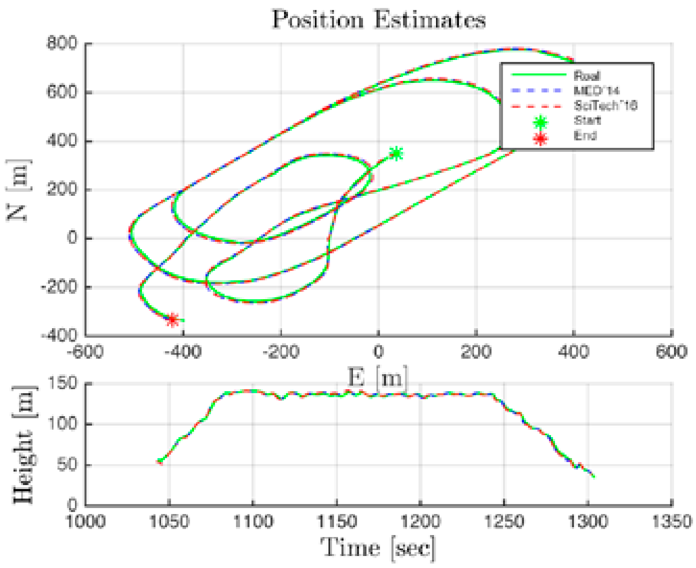


Figure 10: *North-East-Down position estimates for the two nonlinear observers (flat terrain).*

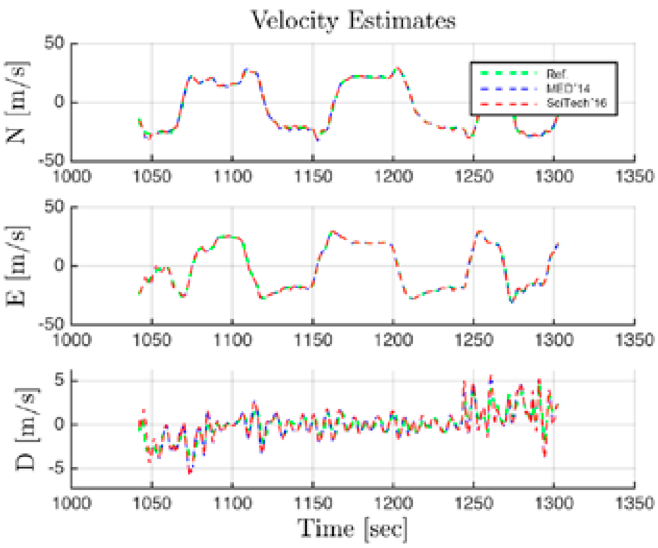


Figure 11: *North-East-Down velocity estimates for the two nonlinear observers (flat terrain).*

RESEARCH AREA: SAFER, SMARTER AND GREENER MARINE OPERATIONS

A numerical and experimental study of a two-dimensional body with moonpool in waves and current

Supervisors: Professors Odd Magnus Faltinsen and Trygve Kristiansen
PhD candidate: Arnt Gunvald Fredriksen

Moonpools are openings in the bottom of ship hulls, often used in marine operations to lower or lift devices such as subsea modules and ROVs. They offer a more protected environment with respect to alternative lowering–lifting procedures, and their application is expected to increase because of rapid development of subsea plants and rising need of year-round operations for repair and maintenance. An important issue is the occurrence of piston-mode resonance for the water column inside the moonpool, characterized by up-and-down fluid motion. The size of the water motion inside the moonpool depends on the damping level, for which a major contribution comes from the vortex shedding at the lower entrance of the moonpool. Careful design is needed to avoid dangerous operational conditions for the water inside. Based on such motivations, this project started within the CoE CeSOS and then continued and ended this year within NTNU AMOS. It investigated piston-mode occurrence and its coupling with the vessel motions in idealized 2D flow conditions, both numerically and experimentally. Numerically, a hybrid solution strategy combining two field methods was proposed.

The developed domain-decomposition approach solves the problem by coupling a Harmonic Polynomial Cell method with a Navier–Stokes Finite-Volume method. The latter handles viscous effects within laminar assumptions and is used in a region near the structure with its moonpool; the former is a very efficient and accurate potential-flow solver and is applied in the rest of the fluid domain (see Figure 12).

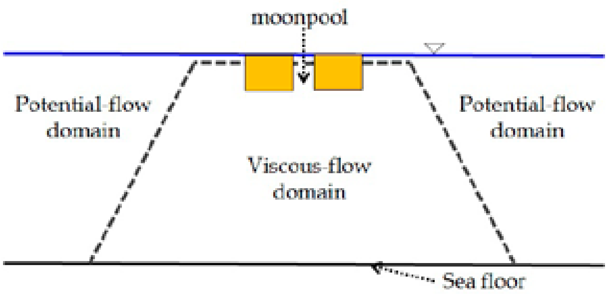


Figure 12: *Sketch of the 2D domain-decomposition strategy.*

The advantage is that relevant phenomena are handled where necessary, and efficiency is preserved. An in-depth convergence analysis has been performed assessing the method reliability and ruling out the influence of the position of the boundary between the two-coupled methods (dashed line in Figure 12). Two versions of the hybrid method were developed: (A) one with linearized free surface and body boundary conditions and (B) the other with fully nonlinear formulation, exact boundary conditions and flow described in a fixed-body coordinate system. The experiments were carried out during this PhD research in a wave flume at the Marine Technology Center (see Figure 13).

They studied two scenarios: forced heave motion with low forward speed and free response to incoming regular waves. Several possible error sources in the model tests were examined. Figure 14 documents very good agreement between the measurements and the fully nonlinear hybrid method B for the Response Amplitude Operators (RAOs) of ship roll motion and free-surface elevation inside the moonpool, for the case of free response in waves. Hybrid method A with linearization (not shown) is less consistent with the measurements in terms of roll motion and is less accurate in modelling the vorticity shed at the bilges.

When a potential-flow solution is used everywhere in the fluid domain (see Figure 14), the vortex shedding at the opening is not handled, leading to RAO overestimations. This means that both (1) viscous effects locally at the moonpool and (2) exact boundary conditions matter. From the analysis, very little water motion is recorded at the moonpool resonance. This is due to cancellation of heave and diffraction effects on the moonpool motion. Moreover, the moonpool affects the heave added-mass and thus the heave natural period. An additional heave

Figure 13: *Experimental setup for 2D moonpool studies.*

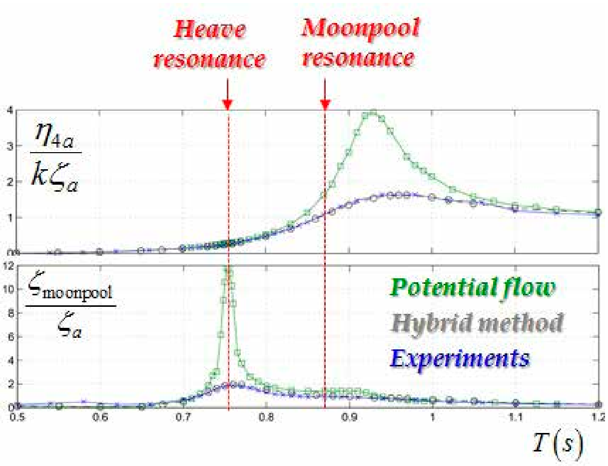


Figure 14: *RAOs for ship roll (top) and moonpool free-surface elevation (bottom) versus the incident-wave period.*

resonance peak is caused with respect to a similar ship without a moonpool and, at wave periods slightly higher than this peak period, the opening lowers the heave. This fact suggests the possibility of using the moonpool concept to minimize the heave motion.

This PhD research inspired a later design of a new suspended-floating bridge. The floating part is elliptically shaped and has two eccentric moonpools for minimization of the roll motion. Thanks to this and related work, Arnt G. Fredriksen won the 2015 prize "Årets Unge Rådgiver".

Media coverage:

- Prize "Årets Unge Rådgiver", awarded 10 November 2015 by the Association of Consulting Engineers (RIF) in Norway. Excerpt from the statement of the jury (translated by the editor): "Fredriksen develops things that haven't been there before. He is innovative and has contributed to the development of new tools and standards, among others within current and wave loads".

Related publications:

- **Fredriksen, Arnt Gunvald; Kristiansen, Trygve; Faltinsen, Odd Magnus.** Wave-induced response of a floating two-dimensional body with a moonpool. *Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences* 2015 ;Volume 373.(2033)
- **Fredriksen, Arnt Gunvald.** A numerical and experimental study of a two-dimensional body with moonpool in waves and current. 2015, PhD thesis, NTNU, Trondheim, Norway

RESEARCH AREA: SAFER, SMARTER AND GREENER MARINE OPERATIONS

Autonomy in complex marine offshore operations

Supervisor: Professor Roger Skjetne
PhD candidates: Bo Zhao, Øivind Kåre Kjerstad, Qin Zhang, Ulrik Jørgensen, Petter Norgren, Svenn Are Tutturen Værnø, Hans-Martin Heyn, Zhengru Ren

Complex marine operations under study by this research group at NTNU AMOS encompass Arctic offshore operations, dynamic positioning (DP) and position mooring (PM) operations in challenging environments, and advanced marine construction operations. Examples of topics under study are DP and PM in harsh open water and ice-covered Arctic offshore fields, ice management operations, underwater vehicles used for mapping and surveillance of ocean conditions and dangers of sea-ice and icebergs, and imagery and sensor-based systems for online monitoring of operational conditions. Two PhD theses were successfully defended, a spin-off company was established, and numerous journal articles and conference papers were published in 2015.

The research of this group started with the KMB Arctic DP project, primarily concentrating on DP in ice and surveillance systems for ice management. The research activities have been continued by the research centre of CoE NTNU AMOS and CRI SAMCoT (Sustainable Arctic Marine and Coastal Technology).

A focus has been on developing smarter DP and PM systems that better understand ice loads and how to handle them. An important foundational study for this work was the phenomenological investigation of ice loads from sea-ice broken by icebreakers conducted by Kjerstad et al. (2015). One of the studied phenomena was the accumulation effect of broken ice pieces against the ship hull, which greatly increases the mean load on the vessel. Another phenomenon is the formation of "force strings" or *contact networks* between the ice floes upstream of the vessel, as illustrated in Figure 15. Such force strings can rapidly build up and correspondingly increase the load on the vessel, and can also rapidly

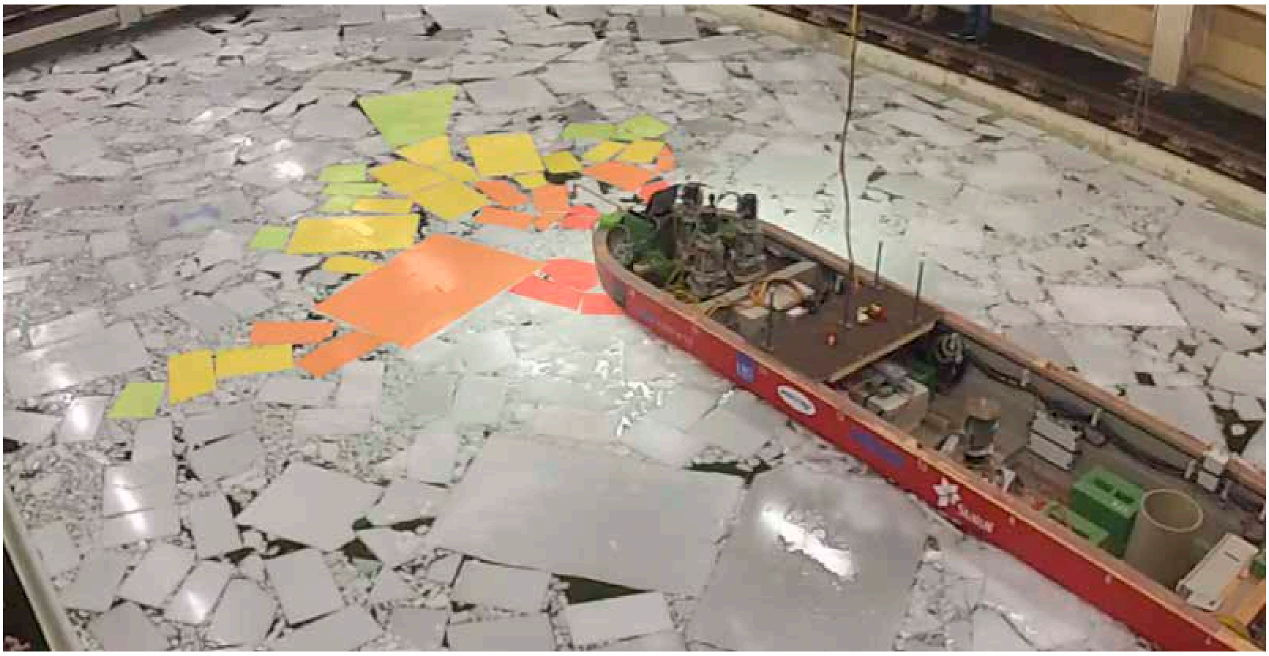


Figure 15 *(HSVA): Formation of contact networks, increasing the loads on an Arctic drillship tested at the ice-basin at HSVA.*

break down and release the load. Such phenomena, and others, give ice loads very different characteristics than open water loads from wind, waves, and currents.

With a better understanding of the behaviour of ice loads, efforts have been made on developing efficient control algorithms, utilizing existing and new sensory information, to compensate such loads in DP or PM operations. If only conventional feedback is available for DP, then this study has shown that hybrid control techniques with resetting of the integral action (or the bias estimate) can significantly improve the transient performance of DP systems. However, the study also shows that intelligent feedforward of IMU measurements can further improve the responsiveness of the DP control system to rapidly handle changing external loads.

Further studies in this field have shown, through the work of Heyn and Skjetne (2015), that a deeper analysis of the acceleration signals when operating in sea-ice, can potentially reveal specific characteristics to identify the limiting mechanism and ice breaking failure mode of the structure-ice interactions. An example is shown in Figure 16. Here, we see the combined time-frequency distribution of the heave-motion accelerations measured by the IMUs installed on the port and starboard forward frames of the icebreaker Frej. Observing the time-synchronized camera images, we find this event to occur when moving in a field of managed ice into an unbroken area, with variations of ice crushing and ice bending failure modes. The ability to distinguish the dominating failure modes of ice breaking gives the possibility to develop even smarter guidance and control algorithms for DP and PM in ice based on reactive strategies.

Moving beyond reactive control strategies, a proactive strategy would, in principle, allow the DP to continuously seek out the minimum effort path through a drifting environmental load field and be "pretensioned" with respect to incoming extreme loads, such as wave trains in open water, and ice ridges and multi-year ice inclusions in sea-ice. Proactive control strategies imply a higher level of autonomy, where a sophisticated "environment monitoring system" interacts with a guidance system that makes intelligent choices for how to operate the vessel. Thus far, we have focused on how to make the necessary measurements of the environment available for a proactive control strategy and for monitoring purposes. This includes use of autonomous underwater vehicles (AUVs) for underwater monitoring of the sea-ice, such as estimating underwater ice topography (Jørgensen and Skjetne, 2015) and detection of ridges and icebergs (see Figure 17). We have also focused on image processing techniques to extract important sea-ice data from visual images by drones or helicopters. The PhD thesis by Zhang (2015) was successfully defended on this subject.

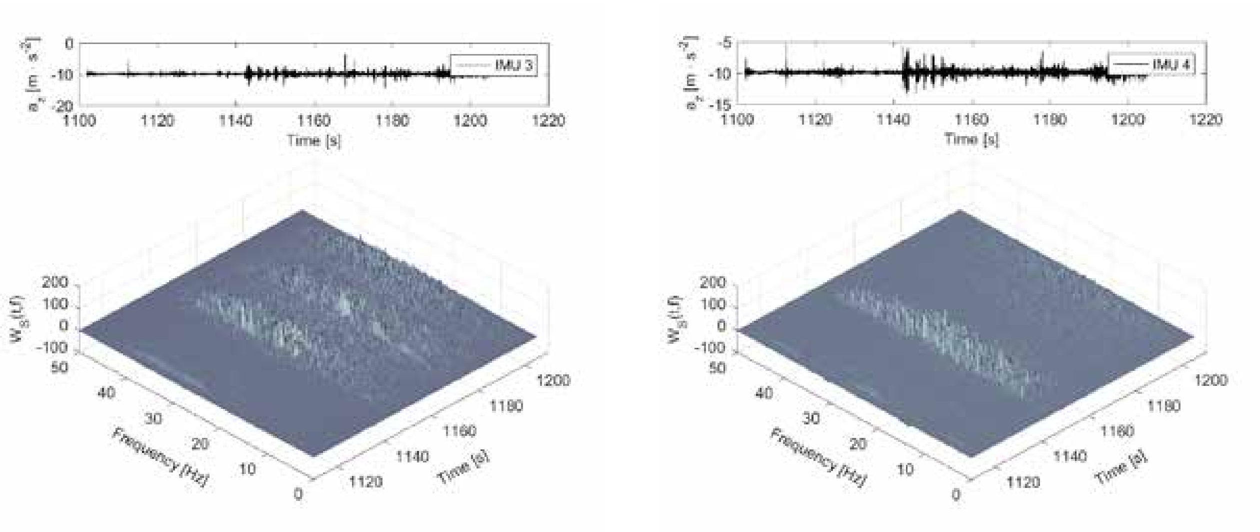


Figure 16: *Time-Frequency distribution of the transition from broken ice to unbroken level-ice.*

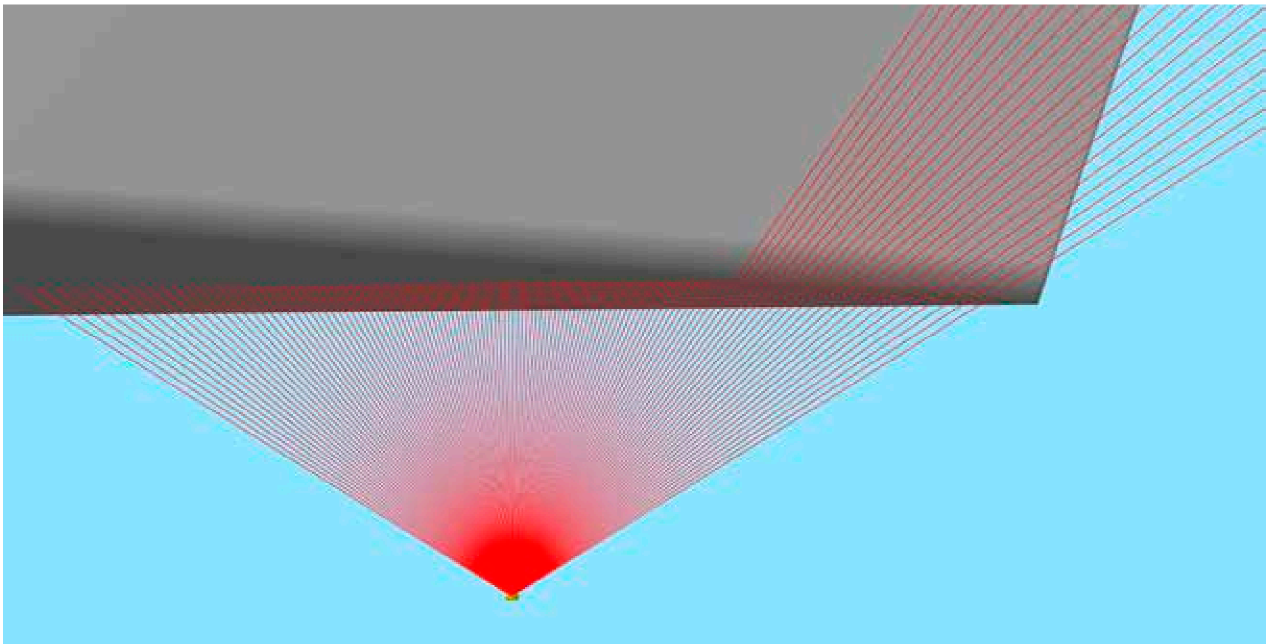


Figure 17: *An AUV mapping a simulated iceberg using multibeam sonar.*

In the field of remotely operated vehicles (ROVs), a research objective has been fault diagnosis to improve robustness to faults in the control system and disturbances in the underwater navigation systems. This resulted in a successfully defended PhD thesis by Zhao (2015). Another objective has been the development of low-cost consumer-grade underwater drones, which was initiated through three MSc theses. This has resulted in the very exciting 2015 establishment of the NTNU AMOS spin-off company BluEye Robotics.

Media coverage:

- Teknisk Ukeblad, Slik fungerer den norske ubåt-dronen til under 20.000 kroner, 17 November 2015: http://www.tu.no/artikler/slik-fungerer-den-norske-ubat-dronen-til-under-20-000-kroner/276000
- Trondheim kommune, Tre finalister til Ung Innovasjonspris, 24 August 2015: https://www.trondheim.kommune.no/content/1117750464/Tre-finalister-til-Ung-Innovasjonspris
- Dagbladet, Christines drone kan revolusjonere forståelsen av havet, 28 October 2015: http://www.dagbladet.no/tag/blueye_robotics
- Adressa.no, Denne NTNU-dronen filmer under vann, 8 February 2016: http://www.adressa.no/nyheter/okonomi/2016/02/07/Denne-NTNU-dronen-filmer-under-vann-12121938.ece
- Trønder-Avisa, Dyp idé vant gjev innovasjonspris, 14 January 2016: http://www.t-a.no/incoming/2016/01/14/Dyp-id%C3%A9-vant-gjev-innovasjonspris-12029891.ece

Related publications:

- **Kjerstad, Øivind Kåre; Metrikin, Ivan; Løset, Sveinung; Skjetne, Roger**. Experimental and phenomenological investigation of dynamic positioning in managed ice. Cold Regions Science and Technology 2015 ;Volume 111. p. 67-79
- **Heyn, Hans-Martin; Skjetne, Roger**. Estimation of Forces caused by Ship-Ice Interaction using on-board Sensor Measurements. Proceedings - International Conference on Port and Ocean Engineering under Arctic Conditions 2015 ;Volume 2015-January.
- **Jørgensen, Ulrik; Skjetne, Roger**. Online reconstruction of drifting underwater ice topography: The 2D case. Asian journal of control 2015 ;Volume 17.(5) p. 1509-1521
- **Zhang, Qin; Skjetne, Roger**. Image Processing for Identification of Sea-Ice Floes and the Floe Size Distributions. IEEE Transactions on Geoscience and Remote Sensing 2015 ;Volume 53.(5) p. 2913-2924
- **Zhao, Bo**. Particle Filter for Fault Diagnosis: Applications to Dynamic Positioning Vessels and Underwater Robotics. PhD thesis, 2015, Norwegian Univ. Science & Technology, Trondheim, Norway.

RESEARCH AREA: SAFER, SMARTER AND GREENER MARINE OPERATIONS

Consequences of accidental and abnormal events on ships and offshore structures

Supervisor: Professor Jørgen Amdahl
PhD candidates: Martin Storheim, Zhaolong Yu

The goal of this research is to develop improved procedures for analysis, design, and control in cases of accidental events, such as groundings and collisions of ships and offshore platforms. Key research tasks are related to assessment by means of nonlinear finite element analysis (NLFEA); the mesh scale effects on strain calculation, accuracy and applicability of various fracture criteria and the effect of structure-fluid interaction.

Structural response in Ship-platform and Ship-ice collisions

Martin Storheim investigated the damage to offshore platforms subjected to ship collisions by means of NLFEA. The sensitivity of the predicted structural damage with respect to mesh size, fracture criteria, and structural damage was studied in detail. A novel way of separating mesh scale effects due to geometric changes and material necking was proposed. An existing fracture criterion (BWH criterion) was extended beyond the onset of instability, where local necking was assumed to occur within a region equal to the plate thickness, as illustrated in Figure 18. The model facilitates the use of relatively coarse shell elements, enabling simulations of large-scale collisions. Furthermore, the model allowed interesting considerations with respect to the effect of strain rate on the plastic flow stress.

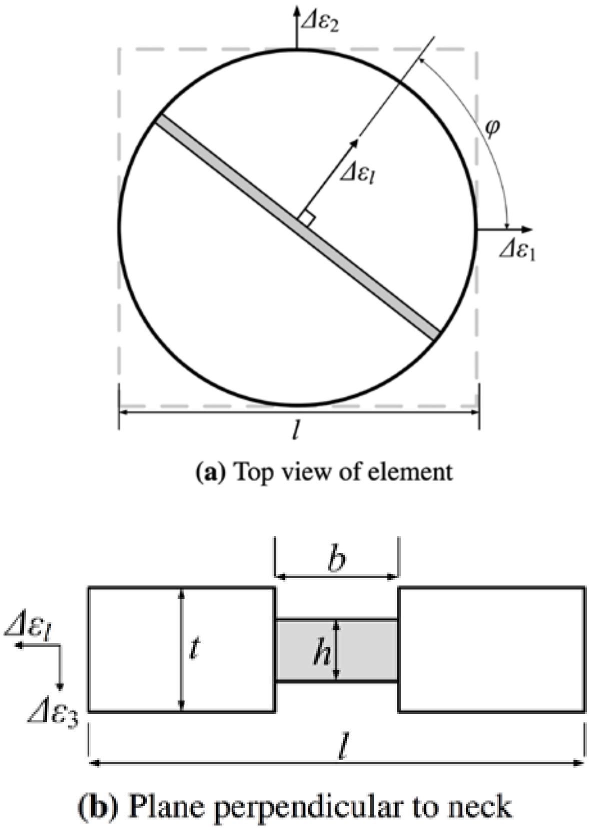


Figure 18: *Fracture model for shell element.*

A large number of fracture models were compared with series of small-scale and large-scale fracture and collision tests. No fracture model performed best in all of the tests, but there were differences with respect to bias and standard variation. Simulation of the collision between the Ropax vessel URD and the ferry Nils Holgerson showed good agreement with real damage patterns.

The response of offshore structures to ship impact was investigated. Emphasis was placed on the interaction between ship deformation and platform deformation. It was found that the resistance to collision can be increased substantially provided that strength design is implemented. To achieve this, jacket braces or stiffened panels in floating platforms must fulfil certain compactness requirements. The present work was coordinated with the DNV GL JIP *Determination of Structural capacity with Nonlinear Finite Element Methods* and some of the results are currently being implemented in the revision of DNV GL, i.e., the recommended practice for design against accidental loads (DNV GL RP C204).

Figure 19: *Actual damage and simulated damage.*

Coupled structure-hydrodynamic simulation of ship collisions

Ship collisions and groundings are highly nonlinear and transient coupled dynamic processes involving large-scale structural deformation and fluid structure interactions. It has long been difficult to include all effects in one simulation. By taking advantage of a user-defined load subroutine, the ship global motions based on potential flow theory was implemented into the nonlinear finite element code LS-DYNA, facilitating a fully coupled six degrees of freedom (6DOF) dynamic simulation of ship collision and grounding accidents (see Figure 20). The effect of forward speed was taken into account. Several impact cases between a rigid plate and a submersible platform were simulated. The force histories obtained with LS-DYNA were used as input to SIMO analysis, and the global motions were virtually identical. It was therefore concluded that the method is capable of predicting the 6DOF global ship motions and the structural deformations with high accuracy. For typical collision speeds, the forward speed effect is limited and may be neglected. The results from the coupled simulations were also compared with predictions based on the external mechanics method. This comparison showed that the external mechanics model captures the dissipated energy only up to the end of the first impact period. When second impacts occur, the decoupled method can be conservative. However, in some collision cases with long durations, the secondary impact can hardly be identified.

Related publications:

- **Storheim, Martin; Amdahl, Jørgen; Martens, Ingo**. On the accuracy of fracture estimation in collision analysis of ship and offshore structures. Marine Structures 2015 ; Volume 44. p. 254-287
- **Storheim, Martin; Amdahl, Jørgen**. On the sensitivity to work hardening and strain-rate effects in nonlinear FEM analysis of ship collisions. Ships and Offshore Structures 2016
- **Storheim, Martin; Alsos, Hagbart Skage; Hopperstad, Odd Sture; Amdahl, Jørgen**. A damage-based failure model for coarsely meshed shell structures. International Journal of Impact Engineering 2015 ; Volume 83. p. 59-75
- **Yu, Zhaolong; Amdahl, Jørgen; Storheim, Martin**. A new approach for coupling external dynamics and internal mechanics in ship collisions. Marine Structures 2016 ; Volume 45. p. 110-132

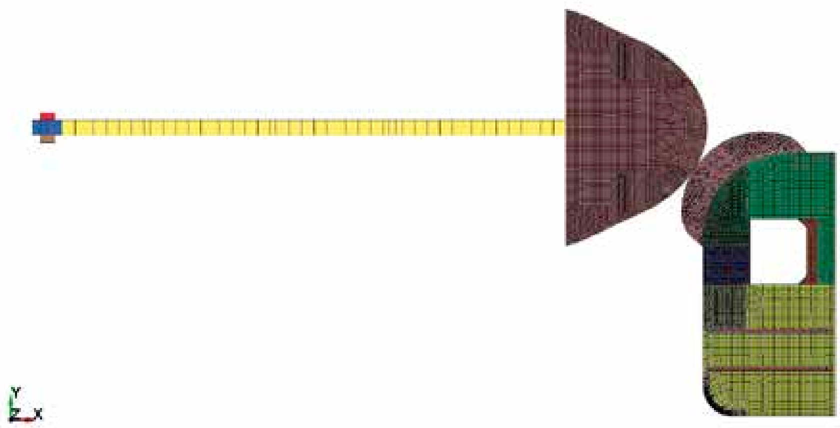


Figure 20: *Ship floating platform column collisions. The beam connected to the detailed bow model is used to model the rigid body motion of the hull.*

RESEARCH AREA: SAFER, SMARTER AND GREENER MARINE OPERATIONS

Improving the performance of dynamic positioning systems using hybrid control methods

Supervisors: Professors Roger Skjetne and Asgeir J. Sørensen
PhD candidates: Astrid H. Brodtkorb, Svenn Are T. Værnø

Marine operations are moving into harsh environments, far from the shore. Demand is increasing for dynamic positioning vessels that can operate for prolonged periods of time in challenging conditions while maintaining safety and energy-efficiency. This research considers improving the performance of DP vessels operating in unknown environments by using hybrid control methods. In 2015, we explored the use of monitoring functions for deciding when to switch in the hybrid controller, ways to fuse information from measurements taken with different sampling times, and improving the transient vessel response using hybrid integral action and observers combining signal-based and model-based parts. The research was conducted at the Norwegian University of Science and Technology, Trondheim, Norway.

Dynamic positioning (DP) vessels that perform operations of longer duration experience changing sea states with varying wind and wave directions, and need to maintain suboptimal heading at times. Large forces and moments act on the vessel, making quick and precise control essential, especially when operating close to other offshore infrastructure.

The tuning of controllers and observers is highly dependent on the ever-changing environment, and thus the use of hybrid controls is a natural choice. To use a hybrid control, one needs switching criteria that can be based on estimates of the environment, events, or performance. Estimating the environment online was investigated in-depth with model-scale experiments in the Marine Cybernetics Laboratory (MCLab; see Figure 21). A DP vessel was exposed to various sea states with different relative headings to see how well the vessel's motions were able to estimate the peak frequency of the incident waves. The heave and pitch motions gave the best estimates, which are used online in the observer.

Figure 21: *Model during experiments in the MCLab.*

Another part of the work considered fusing measurements with different sampling rates in a novel observer. The concept assumes that noisy position measurements are available only occasionally at a non-constant sampling rate of 0.1-4 Hz. Predictions of position between the samples are provided by integrating acceleration measurements, which are available at a high rate of 100 Hz.

We studied improving the transient response of the vessel resulting from a sudden change of the mean forces acting on the hull. Transient responses sometimes arise due to unknown factors, such as wave trains, ice forces, or tension line break, but they are often known and triggered by the operation taking place. Mean loads are usually compensated by the integral action in the controller, which is normally tuned low so it does not induce oscillations from first order waves into the closed loop system. The idea of the proposed hybrid controller is that close to the desired position, the nominal local integrator is active, and when the vessel is far from the setpoint, the global and more aggressive integral action is activated. Figure 22 shows the North position error and that the hybrid integral action controls the vessel back to setpoint faster than the nominal tuning. The hybrid system is analyzed to ensure that the system remains stable during switches.

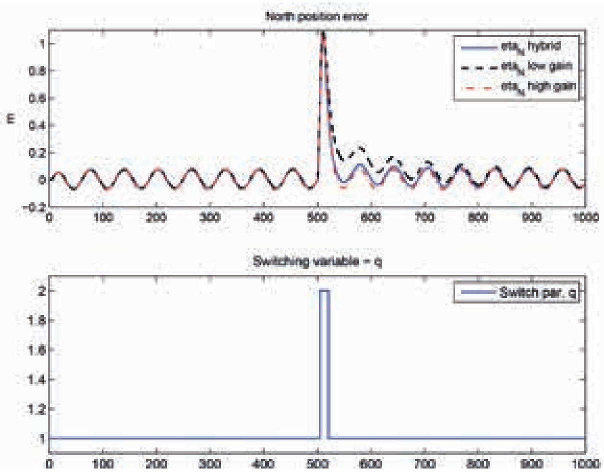


Figure 22: *North position error when using nominal (low gain), global (high gain), and hybrid integral action.*

A model-based observer experiences the same problem when the bias force changes rapidly because the bias estimator dynamics change slowly. A signal-based observer uses acceleration measurements and does not rely on estimating a force bias, and therefore has better performance during transient events. Simulation studies showed that letting the hybrid observer with signal-based and model-based parts choose which estimates to use in the feedback control improved the overall performance of the system (see Figure 23).

During transient events, the signal-based estimates were used in the feedback, and during steady state conditions, the model-based estimates were used.

In 2016, we are continuing our work within hybrid DP to improve the transient response of vessels during DP operations. Full-scale tests are planned for RV Gunnerus in the fall of 2016.

Related publications:

- **Værnø, Svenn Are Tutturen; Skjetne, Roger**. Hybrid Control to Improve Transient Response of Integral Action in Dynamic Positioning of Marine Vessels. IFAC-PapersOnLine 2015 ;Volume 48.(16) p. 166-171
- **Brodtkorb, Astrid H.; Nielsen, Ulrik Dam; Sørensen, Asgeir Johan**. Sea state estimation using model-scale DP measurements. I: Proceedings of OCEANS'15 MTS/IEEE Washington Conference & Exhibition. IEEE conference proceedings 2015 ISBN 978-0-933957-43-5.
- **Brodtkorb, Astrid H.; Teel, Andrew R.; Sørensen, Asgeir Johan**. Sensor-based Hybrid Observer for Dynamic Positioning. I: CDC 2015 - 54th IEEE Conference on Decision and Control, Proceedings. IEEE conference proceedings 2015 ISBN 978-1-4799-7884-7.
- **Brodtkorb, Astrid H.; Værnø, Svenn Are T.; Teel, Andrew R.; Sørensen, Asgeir Johan; Skjetne, Roger**. Hybrid observer for improved transient performance of a marine vessel in dynamic positioning. Submitted to the 10th IFAC Symposium on Nonlinear Control Systems (NOLCOS 2016), Marriott Hotel Monterey, California, USA. August 23-25, 2016

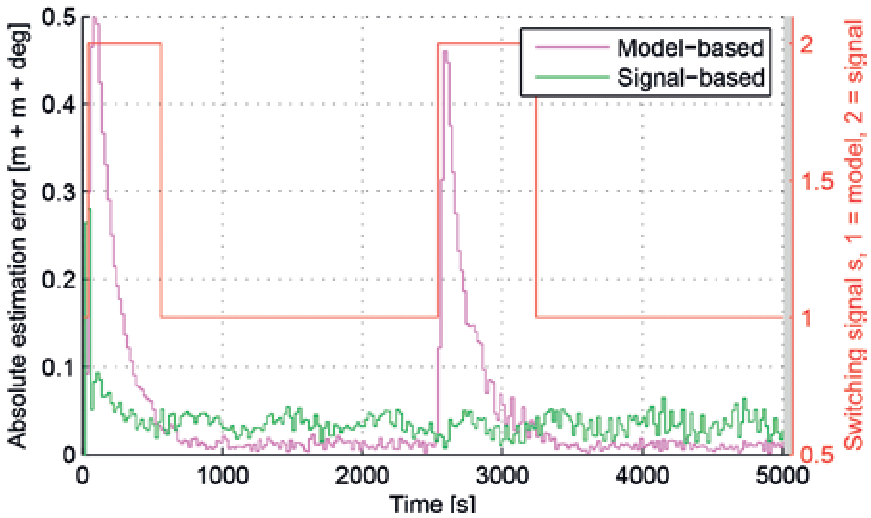


Figure 23: *Estimation error of the signal-based and model-based observer parts, and the switching signal indicating which estimates are used in the closed loop.*

ASSOCIATED RESEARCH PROJECTS

Assessment of operational limits for installation of OWT monopile and transition piece and development of an alternative installation procedure

Project manager: Professor Torgeir Moan
Research associates: Professors Zhen Gao and Gudmund Eiksund, Per Chr. Sandvik
PhD candidates: Lin Li, Wilson Guachamin Acero
Project collaborators: NTNU AMOS, CeSOS, MARINTEK

MARINTEK

Assessment of the operational limits for the installation of offshore wind turbine (OWT) components is important for planning and safe execution of such activities. These limits must be established based on a systematic approach and expressed in terms of allowable motion responses or preferably sea states that can be monitored onboard. The operational limits for the complete installation are governed by limiting parameters that must be identified so that mitigation actions can be applied. Moreover, improved installation procedures are also required for more efficient and economical installation of OWT structural components and systems.

Main research activities:

- Numerical modelling and response analysis of monopile (MP) and transition piece (TP) during installation.
- Assessment of allowable sea states for each installation activity.
- Development of a new concept for installation of a fully assembled offshore wind turbine.

Assessment of the allowable sea states for installation of MP and TP

The installation of MP and TP includes several steps, and the most critical activities are as follows:

1. MP lowering operation.
2. MP hammering operation.
3. TP and MP mating operation.

The numerical methods and models applied for the MP lowering operation consider the shielding effects from the vessel and the radiation damping of the MP, which are included by interpolating the retardation functions at different drafts in the time-domain simulation. These new features are developed and implemented in the code SIMO.

For the MP initial hammering process, the dynamic responses of the coupled vessel-MP system in various seabed penetration depths of the monopile were analysed, and the dynamic model is illustrated in Figure 24.

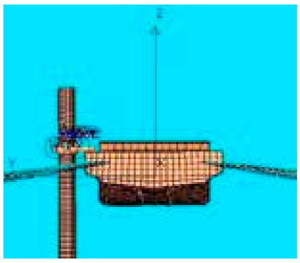


Figure 24: *Dynamic coupled model of vessel and MP during initial hammering process.*

The TP mating operation was studied using the crossing rate method. A typical time-domain simulation of the motion of the TP bottom tip is shown in Figure 25.

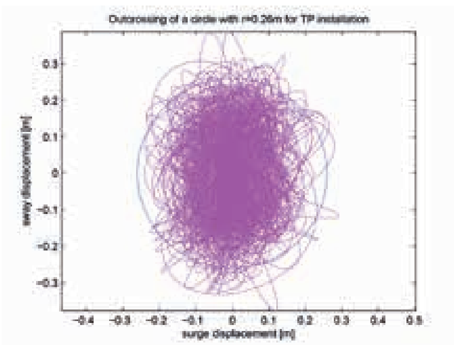


Figure 25: *Horizontal motions and out-crossings of a TP´s bottom tip from a circular limit state (blue) boundary during installation.*

Following the results of the numerical analysis, the dynamic responses for each activity were assessed quantitatively. The critical events and corresponding limiting parameters were identified. By setting the operational criteria, the allowable sea states for each activity were obtained as shown in Figure 26.

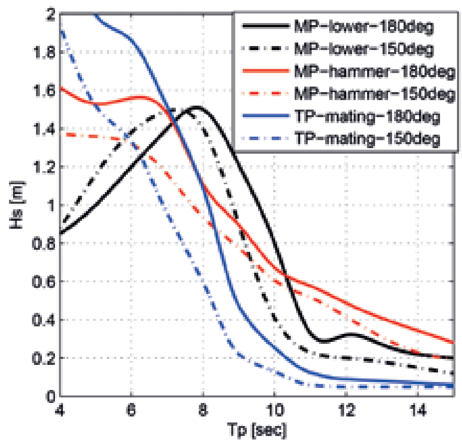


Figure 26: *Allowable sea states, with different headings, for different activities during MP and TP installation by use of a crane barge.*

Development of an alternative method for installation of OWTs

A new procedure for installing a preassembled rotor-tower-nacelle based on the principle of the inverted pendulum was developed. As indicated in Figure 27, it consists of a medium-sized floating crane vessel, a cargo barge, and an upending frame. The novel procedure takes advantage of the shielding effects from the crane vessel on the cargo barge. The performance of the installation concept was assessed by numerical analyses.

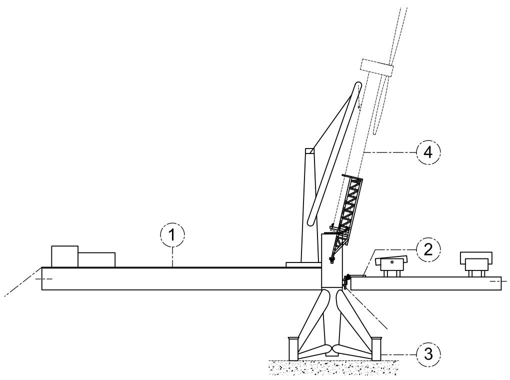


Figure 27: *Upending operation of a preassembled OWT. (1) crane vessel; (2) cargo barge; (3) tripod foundation; (4) OWT.*

Figure 28 shows the time history of dynamic responses during the OWT upending phase.

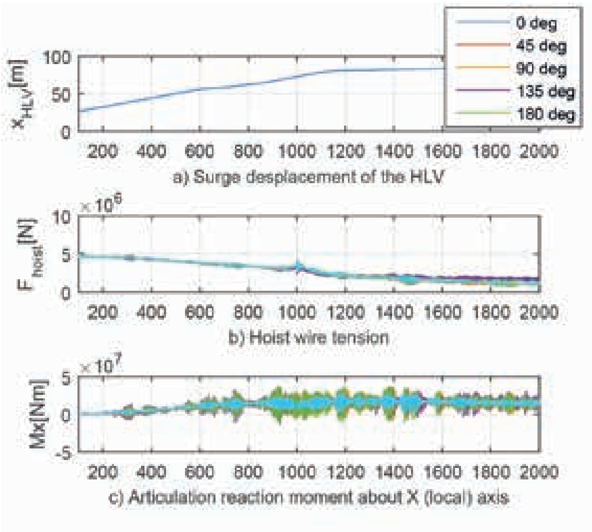


Figure 28: *Typical time histories of dynamic responses during OWT upending.*

Related publications:

- **Guachamin Acero, Wilson Ivan; Moan, Torgeir; Gao, Zhen.** Steady State Motion Analysis of an Offshore Wind Turbine Transition Piece During Installation Based on Outcrossing of the Motion Limit State. I: ASME 2015 34th International Conference on Ocean, Offshore and Arctic Engineering Volume 3: Structures, Safety and Reliability. ASME Press 2015 ISBN 978-0-7918-5649-9
- **Li, Lin; Gao, Zhen; Moan, Torgeir.** Response analysis of a nonstationary lowering operation for an offshore wind turbine monopile substructure. Journal of Offshore Mechanics and Arctic Engineering-Transactions of The Asme 2015 ;Volume 137.(5)
- **Li, Lin; Gao, Zhen; Moan, Torgeir.** Comparative study of lifting operations of offshore wind turbine monopile and jacket substructures considering vessel shielding effects. ISOPE - International Offshore and Polar Engineering Conference. Proceedings 2015 ;Volume 2015-January. p. 1290-1298
- **Li, Lin; Guachamin Acero, Wilson; Gao, Zhen; Moan, Torgeir.** Assessment of allowable sea states during installation of OWT monopiles with shallow penetration in the seabed. Journal of Offshore Mechanics and Arctic Engineering, conditionally accepted
- **Guachamin Acero, Wilson; Gao, Zhen; Moan, Torgeir.** Feasibility study of a novel concept for the installation of the tower and rotor nacelle assembly of offshore wind turbines based on the inverted pendulum principle. Ocean Engineering, conditionally accepted

Design and verification of control system for safe and energy-efficient vessels with hybrid power plants (D2V)

Project manager: Professor Asgeir J. Sørensen
Research associates: Professors Tor Arne Johansen, Roger Skjetne and Ingrid B. Utne, associate professor Eilif Pedersen
PhD candidates: Torstein I. Bø, Michel Rejani Miyazaki, Andreas R. Dahl, Børge Rokseth, Kevin Koosup Yum
Project collaborators: NTNU AMOS, Kongsberg Maritime, DNV GL

Dynamically positioned (DP) vessels with electric power plants in the range of 10 -–80 MW are used in the offshore industry in several safety-critical operations, including drilling, supply, offloading, construction, anchor handling, and production. DP vessels are increasingly used, and they constitute a major part of the national and international maritime activities related to the exploration and exploitation of hydrocarbons and other advanced offshore operations. The development of knowledge and competence in the design and qualification of safe and environmentally robust power and energy management systems for safer and greener offshore vessels is critical for the Norwegian industry.

In 2015, we worked further on the development of the marine hybrid power plant simulator and performed simulations of user cases for the design of control systems. In addition, the Hybrid Power Laboratory was set up, partly funded by the project, to measure the system performance of the power plant including diesel engines, DC/AC electrical systems and energy storage devices (Figure 29). In recent laboratory measurements, we have identified the effect of transient load on fuel consumption and gas emission of the diesel engines. In the test, we applied a sinusoidal load with different frequencies and a fixed amplitude. The result suggests that the increase in fuel consumption due to the transient load is limited to 3.5% (Figure 30).

Figure 29: *Hybrid Power Laboratory.*

Through these activities, the project addresses the following:

- Design and verification of complex systems by system simulations
- Analysis of transient and stationary dynamics on fuel consumption and gas emissions
- Optimal and fault-tolerant control of hybrid power systems on ships and rigs
  - Diesel- and LNG-driven gensets
  - Energy storage using battery banks, capacitor banks, etc.
  - AC and DC systems

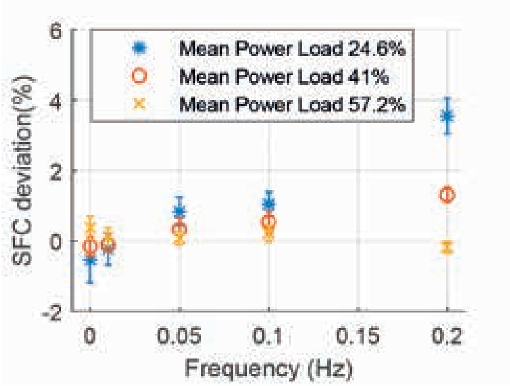


Figure 30: *Deviation of specific fuel consumption (SFC) for transient loads of different frequencies and mean values.*

Efficient stochastic dynamic response analysis for design of offshore wind turbines

Project manager: Professor Torgeir Moan
Research associate: Professor Zhen Gao
PhD candidate: Chenyu Luan
Project collaborators: NTNU AMOS, NOWITECH, Centre for Ships and Ocean Structures (CeSOS)
Project webpage: https://www.sintef.no/projectweb/nowitech

Semi-submersible floating wind turbines might be a solution for economically harvesting wind energy at a wide range of water depths. To promote the development of semi-submersible wind turbines, this project addresses 1) development of an accurate and efficient time-domain approach for determining responses of floating wind turbines in wind and waves, 2) development of simplified methods for design and analysis of semi-submersible wind turbines, and 3) development of a milestone novel reference semi-submersible wind turbine for model tests and numerical comparison.

A design of a 5-MW braceless steel semi-submersible wind turbine has been developed and considered as the basis for a 1:30 scale model tested in the towing tank and ocean basin of MARINTEK using hybrid testing techniques.

An efficient time-domain approach with a focus on the determination of global forces and moments in structural components of the semi-submersible floater has been developed and is being validated against special cases for which other software exists and will be checked against experiments.

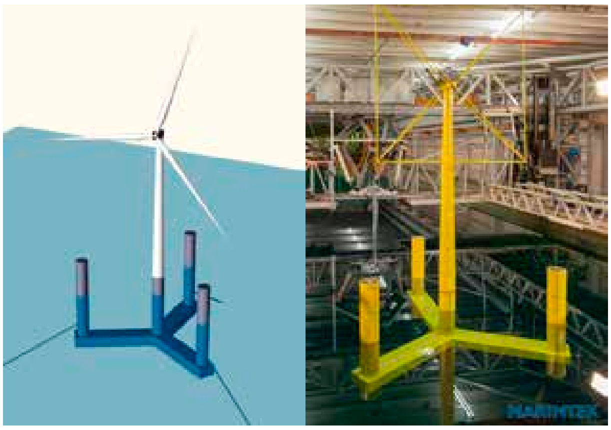


Figure 31: *The 5-MW braceless semi-submersible wind turbine concept (left) and the 1:30 scale model tested at MARINTEK using hybrid testing techniques.*

Media coverage:

- Marintek, New and more effective model test, November 2015, https://www.sintef.no/en/marintek/news/new-and-more-effective-model-test

Related publication:

- **Luan, Chenyu; Gao, Zhen; Moan, Torgeir.** Design and analysis of a braceless steel 5-MW semi-submersible wind turbine. The 35th International Conference on Ocean, Offshore and Arctic Engineering, Paper No. OMAE2016-54848, June 19-24, 2016, Busan, South Korea

Experimental and numerical study of the combined wind/wave energy concept SFC in extreme and operational environmental conditions

Project manager: Professors Torgeir Moan and Zhen Gao
Research associate: Dr Konstantinos Michailides
Project collaborators: NTNU AMOS, CeSOS, MARINA Platform Project
Project webpage: http://www.marina-platform.info

The combined wind/wave energy concept Semi-submersible Flap Combination (SFC), developed by CeSOS in the MARINA Platform Project, has been tested at a 1:50 scale in the Ocean Basin of Ecole Centrale Nantes (ECN), France, in both operational and extreme conditions (Figure 32), to study the functionality and survivability of the concept, respectively.

In the functionality test, the wind turbine was forced to rotate by a motor to generate the equivalent thrust force, and the power take-off of the wave energy converters (WECs) was modelled as a rotary damper with a constant damping level. Numerical analysis of the scaled model of the SFC concept was performed using the software Simo-Riflex. Figure 33 shows good agreement regarding the WEC power between the numerical and experimental results.

The survivability test in which the wind turbine is parked and the WECs are free to rotate indicates very good performance of the combined concept in extreme wind and wave conditions. The WECs do not significantly affect the motion responses of the floater or the structural responses in the tower and mooring lines.

The peak of the produced power is observed for a wave period near the WEC's measured natural period of rotation. The differences between experimental and numerical results increase near the resonance of the rotation of WEC, which is attributed to the uncertainties of the rotation motion's damping model that was used in the numerical analysis.

Related publications:

- **Michailidis, Konstantinos; Gao, Zhen; Moan, Torgeir.** Response Analysis of the Combined Wind/Wave Energy Concept SFC in Harsh Environmental Conditions. Renewable Energies Offshore - 1st International Conference on Renewable Energies Offshore, RENEW 2014, 2015, Pages 877-884; 2014-11-24 - 2014-11-26
- **Gao, Zhen; Moan, Torgeir; Wan, Ling; Michailidis, Konstantinos.** Comparative Numerical and Experimental Study of two Combined Wind and Wave Energy Concepts. Journal of Ocean Engineering and Science, 2016

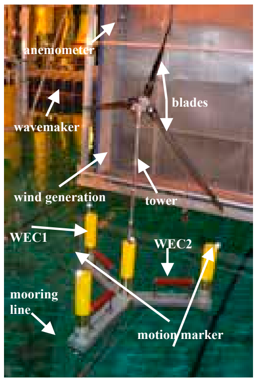


Figure 32: *Physical model setup of the SFC and its WECs.*

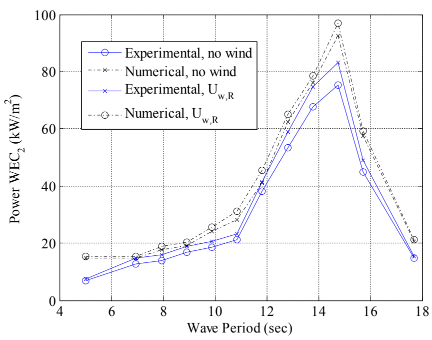


Figure 33: *Comparison of the produced power of the WEC by numerical analysis and model tests.*

External sea loads and internal hydraulics of closed flexible cages

Project manager: Dr Pål Lader
Research associates: Dr Zolt Volent, Trond Rosten, professors Asgeir J. Sørensen and Odd M. Faltinsen, associate professor Dave Fredriksson, assistant professor Jud DeCew
PhD candidate: Ida Marlen Strand
Project collaborators: NTNU AMOS, Botngaard AS, Smøla Klekkeri og Settefiskanlegg AS, Kobbevik og Furuholmen Oppdrett AS, Lingalaks AS, Xylem Water Solutions Norge AS, Aqualine AS, Osland Havbruks AS, Yara-Praxair AS
Project webpage: http://www.sintef.no/en/projects/external-sea-loads-and-internal-hydraulics-of-clos

Recent environmental considerations, such as salmon lice, escape of farmed fish and release of nutrients, have prompted the Norwegian aquaculture industry to consider the use of closed fish production systems. The use of such systems is amongst other suggestions also considered as potential way to expand salmon production in Norway.

In a closed system, a farmer can target increased control of how fish are exposed to pathogens, parasites, algae or pollution by controlling the flow and quality of water entering and exiting the containment volume in an attempt to establish a more bio-secure production environment. The use of these systems can also contribute to changes in production regimes—e.g., larger smolts and a shorter on-growing phase in sea.

Very few ocean structures exist with large, heavily compliant submerged components, and there is presently limited existing knowledge about how aquaculture systems with flexible closed cages will respond to external sea loads. A closed bag will experience an increase in hydrodynamic drag compared with a net-based structure. In addition, the flexibility and deformation of the bag is closely coupled to the hydrodynamic forces, making the hydrodynamic load far more difficult to understand than that of a rigid structure. Therefore, techniques to estimate external forces, dynamic movements and internal stresses must be investigated to limit the risk of fish escaping because of structural collapse or operational failures.

In addition to the external forces and deformation issues, the enclosed body of water must be properly maintained to achieve good water quality, fish welfare and high bio-security. It is expected that the flow patterns within the containment bag will be difficult to understand because they will be dependent on shape and pumping rates. The flexible structure will have to be designed with reasonable water flow to supply dissolved oxygen and remove carbon dioxide and waste products (solid and dissolved).

Several sets of experiments with small-scale models of flexible bags have been conducted at the United States Naval Academy's towing tank in Annapolis, USA, and at the MC-Lab at Tyholt in Trondheim. Different bag geometries were investigated, and tests were conducted in both waves and current.

Media coverage:
- Gemini.no, Stenger lakselusa ute, 25 February 2014: http://gemini.no/2014/02/stenger-lakselusa-ute/
- Forskning.no, Lukkede oppdrettsanlegg utfordrer naturkreftene, 19 December 2013: http://forskning.no/fisk-oppdrett-klima-materialteknologi/2013/12/lukkede-oppdrettsanlegg-utfordrer-naturkreftene
- Intrafish.no, Fremtidens havbruksforskere, 12 December 2014: http://www.intrafish.no/norsk/nyheter/article1402708.ece
- Forskningsradet.no, Ny generasjon havbruksforskere, 5 December 2013: http://www.forskningsradet.no/prognett-havbruk/Nyheter/Ny_generasjon_havbruks-forskere/1253990940279

- Forskningsradet.no, Lukkede anlegg utfordrer naturkreftene, 5 December 2013: http://www.forskningsradet.no/prognett-havbruk/Nyheter/Lukkede_anlegg_utfordrer_naturkreftene/1253990942205
- Forskningsradet.no, Nye løsninger på de store utfordringene, 18 December 2014: http://www.forskningsradet.no/prognett-havbruk/Nyheter/Nye_losninger_pa_de_store_utfordringene/1254004026910

Related publications:

- **Lader, Pål; Fredriksson, David W.; Volent, Zsolt; DeCew, Jud; Rosten, Trond Waldemar; Strand, Ida** Marlen**.** Drag forces on, and deformation of, closed flexible bags. Journal of Offshore Mechanics and Arctic Engineering-Transactions of The Asme 2015 ;Volume 137.(4)
- **Lader, Pål; Fredriksson, David W.; Volent, Zsolt; Strand, Ida Marlen; Rosten, Trond Waldemar.** Wave response of closed flexible bags. Submitted to the 35th International Conference on Ocean, Offshore and Arctic Engineering, June 19-24, 2016, Busan, South Korea.

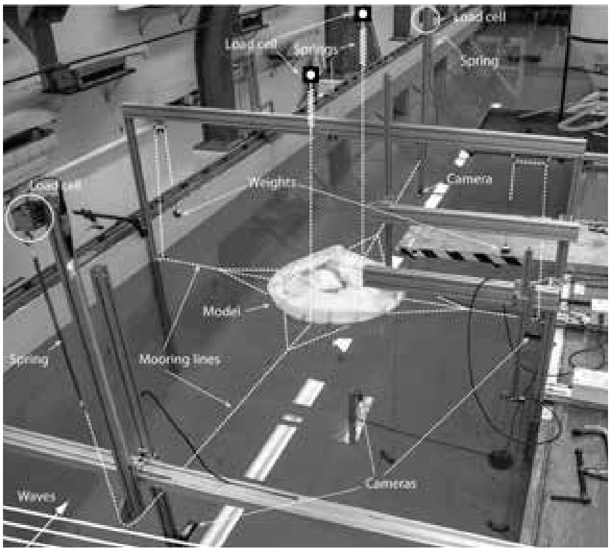


Figure 34: *Wave experiments: laboratory setup.*

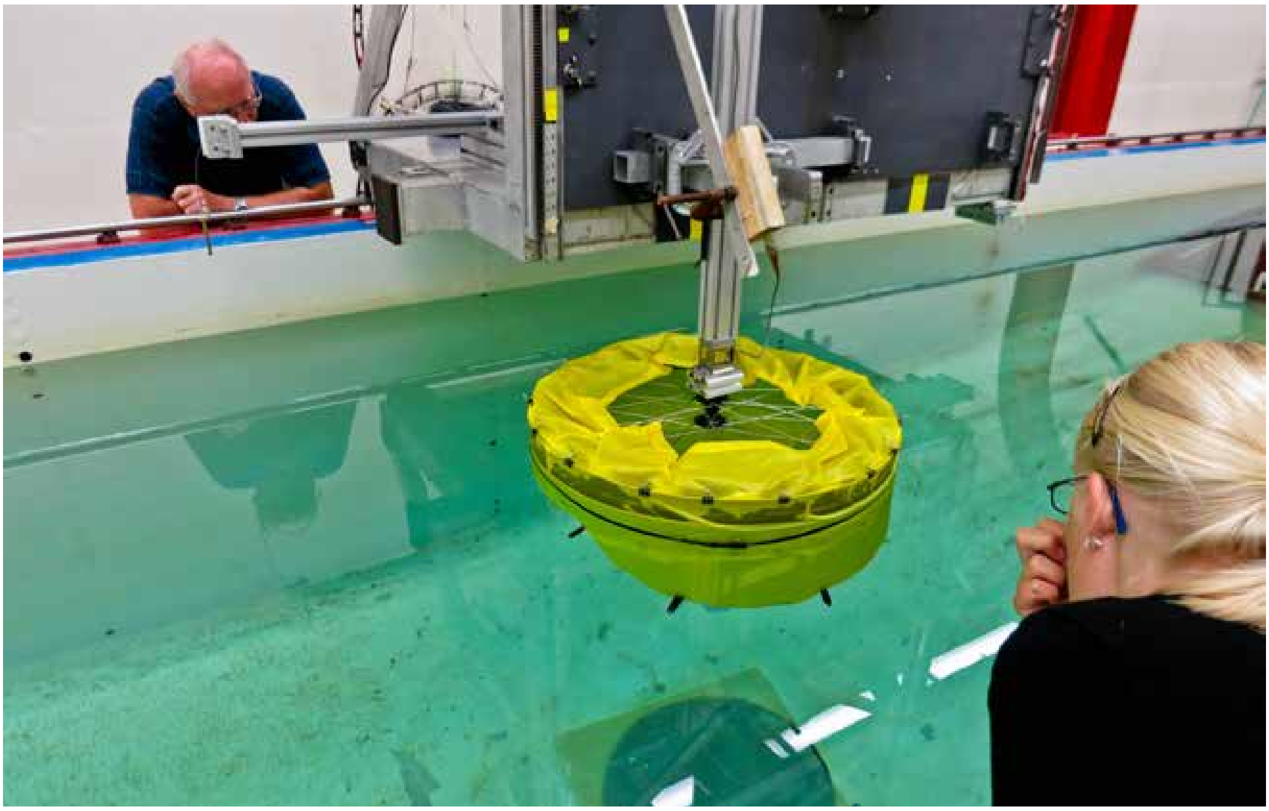


Figure 35: *Senior Scientist Zsolt Volent and PhD candidate Ida Strand study the bag model ready for testing in the towing tank.*

Fatigue damage analysis of drivetrains in land-based and floating TLP, spar and semi-submersible wind turbines

Project manager: Professor Torgeir Moan
Research associates: Amir R. Nejad, Dr Erin E. Bachynski, professor Zhen Gao, Dr Marit Kvittem, Chenyu Luan
Project collaborators: NTNU AMOS, CeSOS, DNV GL, MARINTEK, NOWITECH

This project addresses the feasibility of using a 5 MW drivetrain that is designed for a land-based turbine on four types of floating wind turbines: namely, a spar, a TLP and two semi-submersibles. The focus is on introducing first principles to estimate the fatigue damage of mechanical components inside the gearbox and main bearings, considering representative environmental conditions, ranging from cut-in to cut-out wind speeds. For floating wind turbines, relevant wave conditions are also considered. All wind turbines are intended to follow similar power curves, but differences in the control system are allowed.

A decoupled analysis approach is employed for the drivetrain response analysis by first employing an aero-hydro-servoelastic code in the global analysis. Motions, moments and forces obtained in the global analysis are then applied on the gearbox multibody model to generate the forces on gears and bearings. The results suggest that the main bearings of the main shaft, which are located the gearbox, experience more damage in floating wind turbines than in land-based ones; see, e.g., Figure 36. The highest main bearing damage is observed for the spar floating wind turbine. The large wave-induced axial load on the main shaft is found to be the primary reason for this high damage in the spar wind turbine. Other bearings and gears inside the gearbox of floating wind turbines experience damage that is equal to or even less than those in land-based turbines. It is emphasized that the results presented in this study are based on a drivetrain with two main bearings, which considerably reduces the non-torque loads on the gearbox compared with a single bearing support.

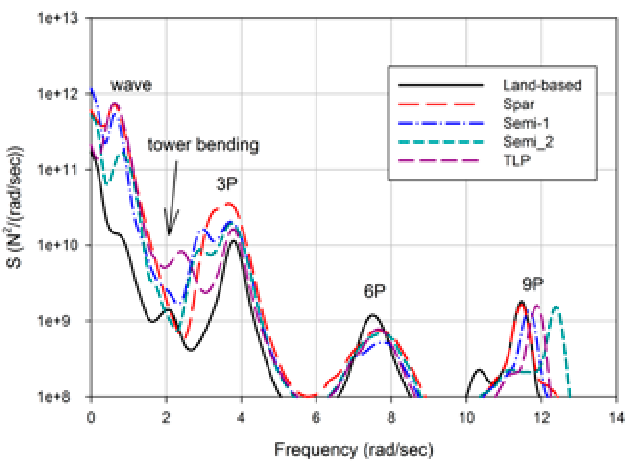


Figure 36: *Response spectra of bearing load for the downwind main bearing.*

Related publications:

- **Rasekhi Nejad, Amir; Bachynski, Erin Elizabeth; Gao, Zhen; Moan, Torgeir.** Fatigue Damage Comparison of Mechanical Components in a Land-based and a Spar Floating Wind Turbine. Procedia Engineering 2015 ;Volume 101.(C) p. 330-338
- **Rasekhi Nejad, Amir; Bachynski, Erin Elizabeth; Kvittem, Marit Irene; Luan, Chenyu; Gao, Zhen; Moan, Torgeir.** Stochastic dynamic load effect and fatigue damage analysis of drivetrains in land-based and TLP, spar and semi-submersible floating wind turbines. Marine Structures 2015 ;Volume 42. p. 137-153

Fault-tolerant inertial sensor fusion for marine vessels (MarineINS)

Project manager: Professor Thor I. Fossen
Research associate: Professor Tor Arne Johansen
PhD candidates: Torleiv H. Bryne, Robert Rogne
Project collaborators: NTNU AMOS, Rolls-Royce Marine
Project web page: http://www.itk.ntnu.no/english/research/maroff13

The Fault-Tolerant Inertial Sensor Fusion for Marine Vessels (Marine INS) project for marine vessels is funded by the Research Council of Norway via MAROFF and Rolls-Royce Marine. The project has developed new architectures and strapdown inertial navigation algorithms for dynamically positioned ships using nonlinear observer theory. In this context, focus has been placed on using low-cost micro-electro-mechanical (MEMS) sensors in combination with various position reference systems to provide motion and position measurements with better accuracy and reliability. The sensor system is triple redundant, and software algorithms are employed to handle faults and failure situations.

Nonlinear strapdown inertial navigation system for marine vessel aided by GNSS

The measurement quality of GNSS during marine operations varies over time. Inherently, GNSS quality changes should be handled when GNSS is utilised as an aid in inertial navigation systems. A nonlinear observer for the estimation of position, velocity and attitude with time-varying gains for high-performance sensor fusion based on GNSS quality and other quality indicators has been developed. In addition, observers to detect faults have been developed to robustify the navigation system.

A triple-redundant INS was installed onboard a supply vessel in 2015 to validate the software algorithms. The results from the experiments will be reported in 2016. The onboard computer system for data logging contains three ADIS 16485 IMUs from Analogue Devices and are interfaced with the ship GNSS.

Related publications:

- **Bryne, Torleiv Håland; Fossen, Thor I.; Johansen, Tor Arne.** Design of Inertial Navigation Systems for Marine Craft with Adaptive Wave Filtering aided by Triple-Redundant Sensor Packages. *International Journal of Adaptive Control and Signal Processing 2015*
- **Bryne, Torleiv Håland; Fossen, Thor I.; Johansen, Tor Arne.** A Virtual Vertical Reference Concept for GNSS/INS Applications at the Sea Surface. IFAC-PapersOnLine 2015 ;Volume 48.(16) p. 127-133
- **Bryne, Torleiv Håland; Fossen, Thor I.; Johansen, Tor Arne.** Nonlinear Observer with Time-Varying Gains for Inertial Navigation Aided by Satellite Reference Systems in Dynamic Positioning. Mediterranean Conference on Control and Automation 2014 p. 1353-1360
- **Rogne, Robert Harald; Johansen, Tor Arne; Fossen, Thor I.** On attitude observers and inertial navigation for reference system fault detection and isolation in dynamic positioning. I: Proceedings of the 14th European Control Conference 2015 (ECC 2015). IEEE conference proceedings 2015 ISBN 9781467371605. p. 3665-3672
- **Rogne, Robert Harald; Johansen, Tor Arne; Fossen, Thor I.** Observer and IMU-based Detection and Isolation of Faults in Position Reference Systems and Gyrocompasses with Dual Redundancy in Dynamic Positioning. Proceedings of the IEEE Conference on Control Applications 2014 p. 83-88

Innovative training network for autonomous unmanned aerial systems for marine and coastal monitoring (MarineUAS)

Project manager: Professor Tor Arne Johansen
Research associates: Professor Thor I. Fossen, adjunct associate professor Rune Storvold
PhD candidates: Anthony Hovenburg, Cees van Keulen, Jonatan Olofsson, Christopher Rodin, Andreas Wenz
Project collaborators: NTNU AMOS, University of Porto, Instituto Superior Tecnico Lisbon (IST), University of Sevilla, Linköping University, Honeywell, Maritime Robotics, NORUT Tromsø, Center for Advanced Aerospace Technologies (CATEC)
Project webpage: www.marineuas.eu

MarineUAS is an EU-funded doctoral program to strategically strengthen research training of Autonomous Unmanned Aerial Systems for Marine and Coastal Monitoring. It is a comprehensive researcher training program across a range of partners in several countries designed to have a high impact on the training of individual researchers for their knowledge, skills and their future careers. MarineUAS has established a unique cooperative environment. It benefits from the partners' extensive and complementary knowledge, field operational experience, and experimental facilities.

Why MarineUAS?

The need to protect and manage the vulnerable natural environment and marine resources in a sustainable manner is an important policy that is manifested in European legislation such as the European Strategy for Marine and Maritime Research.

Moreover, the drive towards activities in more remote locations and harsher environments demands new approaches and technologies. A key enabling technology is the increased use of autonomous unmanned aerial vehicle systems (UAS) instead of manned aircraft and satellite-based remote sensing, oftentimes exploiting strong collaborative links with buoys, ships and autonomous marine vehicles for in situ observations.

UAS offers potential advantages such as high endurance, reduced cost, increased flexibility and availability, rapid deployment, higher accuracy or resolution, and reduced risk for humans and negative impact on the environment.

Figure 37: *European countries have vast coasts and economic zones that extend far into the Atlantic and Arctic Oceans and are challenging to monitor and manage.*

Doctoral training in MarineUAS

Expanding on the existing doctoral programs it combines cutting edge training-by-research, high-quality supervision, complementary and transferable skills training, secondments, hands-on UAS operator training, cross-disciplinary skillsets, and a series of network-wide training events that cover UAS technology, rules and regulations, operations in non-segregated airspace, air traffic management, marine and coastal monitoring and science, and the integration of the air, surface and underwater segments.

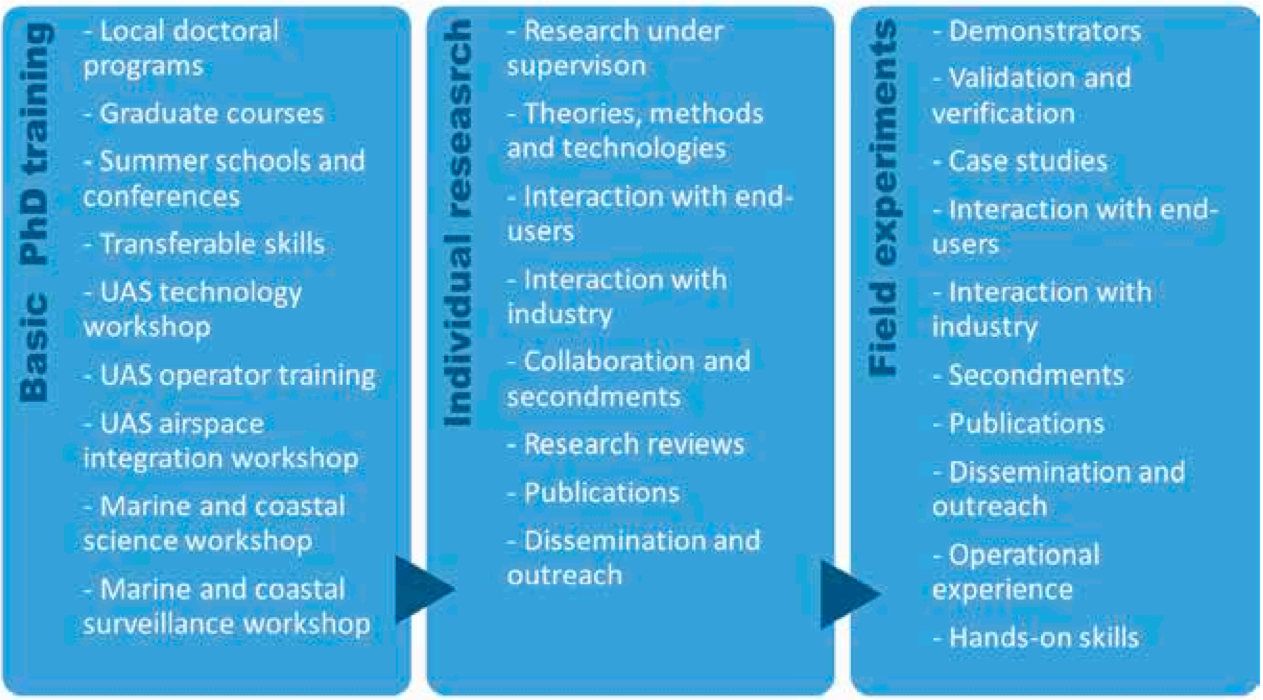


Figure 38: *MarineUAS recruits and trains doctoral fellows via a specially developed and unique training program designed based on the EU Principles for Innovative Doctoral Training.*

Low-cost integrated navigation systems using nonlinear observer theory (LowCostNav)

Project manager: Professor Thor I. Fossen
Research associates: Professors Tor Arne Johansen and Oddvar Hallingstad, Dr Håvard F. Grip
PhD candidates: Sigurd M. Albrektsen, Kasper Trolle Borup, Jakob M. Hansen
Project collaborators: NTNU AMOS, UNIK, Maritime Robotics, Norwegian Defence Research Establishment (FFI)
Project web page: http://www.itk.ntnu.no/english/research/lowcostnav/Hovedside

The low-cost integrated navigation (LowCostNav) project, which is funded by the Research Council of Norway via FRIPRO, has developed nonlinear observers for position, velocity and attitude (PVA) estimation. The project has developed algorithms that can replace the extended Kalman filter (EKF). The nonlinear observers have similar performance to the EKF, but there is a significant reduction in the computational footprint. LowCostNav focuses on nonlinear observer theory for estimation of PVA, and rigorous mathematical proofs for global exponential stability (GES) are provided. Thus, performance and robustness can be guaranteed and quantified. The development of effective computer algorithms that can be implemented using only a fraction of the source code footprint while representing computational complexity compared with a standard EKF implementation is also possible. These algorithms simplify implementation, maintenance, software verification, and documentation. The software can be used in different applications, such as low-cost consumer electronics, cars, and navigation systems for AUVs, ships, and UAVs.

Highlights

A complete navigation solution for PVA determination has been developed using a nonlinear observer framework, which guarantees that the origin of the estimation error dynamics is GES. This problem is a difficult mathematical problem because the attitude estimation problem is highly nonlinear. This study has been extended to include time-delayed GNSS measurements. A payload module for the Penguin B fixed-wing UAV was constructed in 2014, and the observers have been experimentally validated in 2015 with excellent results.

Related publications:

- **Grip, Håvard Fjær; Fossen, Thor I.; Johansen, Tor Arne; Saberi, Ali.** Globally Exponentially Stable Attitude and Gyro Bias Estimation with Application to GNSS/INS Integration. Automatica 2014 ;Volume 51. p. 158-166
- **Hansen, Jakob Mahler; Fossen, Thor I.; Johansen, Tor Arne.** Nonlinear Observer for INS Aided by Time-Delayed GNSS Measurements - Implementation and UAV Experiments. I: 2015 International Conference on Unmanned Aircraft Systems (ICUAS). IEEE conference proceedings 2015 ISBN 978-1-4799-6009-5. p. 157-166
- **Johansen, Tor Arne; Cristofaro, Andrea; Sørensen, Kim; Hansen, Jakob Mahler; Fossen, Thor I.** On Estimation of Wind Velocity, Angle-of-Attack and Sideslip Angle of small UAVs using Standard Sensors. I: 2015 International Conference on Unmanned Aircraft Systems (ICUAS). IEEE conference proceedings 2015 ISBN 978-1-4799-6009-5. p. 510-519
- **Johansen, Tor Arne; Fossen, Thor I.** Nonlinear Observer for Inertial Navigation Aided by Pseudo-Range and Range-Rate Measurements. I: Proceedings of the 14th European Control Conference 2015 (ECC 2015). IEEE conference proceedings 2015 ISBN 9781467371605. p. 1673-1680

Next-generation subsea inspection, maintenance and repair operations (NextGenIMR)

Project manager: Professor Ingrid Schjølberg
Research associates: Professors Ingrid Schjølberg, Ingrid B. Utne, Tor B. Gjersvik and Thor I. Fossen
PhD candidates: Jeevith Hegde, Bård B. Stovner, Eirik H. Henriksen
Project collaborators: NTNU AMOS, FMC Technologies, Statoil, SINTEF, Research Council of Norway

Maintaining high regularity within subsea facilities requires reliable installed equipment but also *efficient methods for inspection, condition monitoring and early detection of equipment faults.* NextGenIMR develops robust perception methods for localization and positioning of underwater vehicles carrying intervention tools. This is the first step towards autonomy in IMR operations. Moreover, the project focuses on development of methods for collision-free motion planning for autonomous subsea inspection and light intervention operations. This is important in the pre-phase when the underwater vehicles are moving towards a facility and in the operational phase when a tool is positioned before the intervention. The project also has a strong focus on subsea factory design for autonomous intervention as well as the development of tools and methods for online risk management during IMR operations. The project especially addresses autonomous platforms, but the results are applicable to cable-connected ROVs that will shift from manual to automatic control with autonomous functions. A dynamic simulator is under development using the MORSE and MOOS frameworks. NextGenIMR results will be tested, verified and demonstrated in full-scale test beds available at NTNU and among industry partners. The technology will be highly relevant for IMR operations in fish farms and deep sea mining. The project has published five articles in international peer-reviewed conferences.

Related publications:

- **Hegde, Jeevith; Utne, Ingrid Bouwer; Schjølberg, Ingrid; Thorkildsen, Brede.** Application of fuzzy logic for safe autonomous subsea IMR operations. I: Safety and Reliability of Complex Engineered Systems. CRC Press 2015 ISBN 9781138028791. p. 415-422
- **Hegde, Jeevith; Utne, Ingrid Bouwer; Schjølberg, Ingrid**. Applicability of current remotely operated vehicle standards and guidelines to autonomous subsea IMR operations. I: Proceedings ASME 2015 34th International Conference on Ocean, Offshore and Arctic Engineering Volume 7: Ocean Engineering. ASME Press 2015 ISBN 978-0-7918-5655-0.
- **Henriksen, Eirik Hexeberg; Gjersvik, Tor Berge; Thorkildsen, Brede**. Positioning of subsea modules using an automated ROV. I: OCEANS 2015 - Genova. IEEE conference proceedings 2015 ISBN 978-1-4799-8736-8.
- **Lekkas, Anastasios M.; Candeloro, Mauro; Schjølberg, Ingrid**. Outlier rejection in underwater Acoustic position measurements based on prediction errors. IFAC-PapersOnLine 2015 ;Volume 48.(2) p. 82-87
- **Schjølberg, Ingrid; Utne, Ingrid Bouwer**. Towards autonomy in ROV operations. IFAC-PapersOnLine 2015 ;Volume 48.(2) p. 183-188

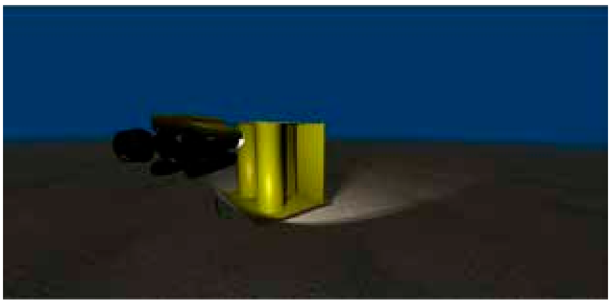


Figure 39: *Dynamic ROV simulator.*

Numerical analysis of the dynamic response of an offshore wind turbine under wind and ice loads

Project manager: Professor Torgeir Moan
Research associates: Dr Wei Shi, professor Zhen Gao
Project collaborators: NTNU AMOS, CeSOS

The goal of this study is to develop a coupled numerical model to study the dynamic responses of offshore wind turbines in level ice.

In regions with cold climates, such as the Baltic Sea, a good understanding of ice loads is essential for the design of a reliable and cost-effective support structure for offshore wind turbines. In this project, a semi-empirical numerical model for ice–structure interaction was coupled to the aero-hydro-servo-elastic simulation tool HAWC2 (Figure 40). It is found that the coupling between the ice loads and the structural responses of the monopile-type wind turbine is important to consider and leads to larger ice-induced dynamic responses compared with those implied by the IEC and ISO standards (Figure 41).

The study of a spar floating wind turbine shows that non-simultaneous bending failure is dominant for the spar wind turbine in operation. The response of the spar wind turbine at the ice breaking frequencies was found to be significant.

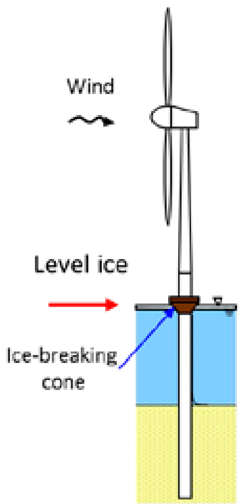


Figure 40: *Monopile wind turbine with ice-breaking cone.*

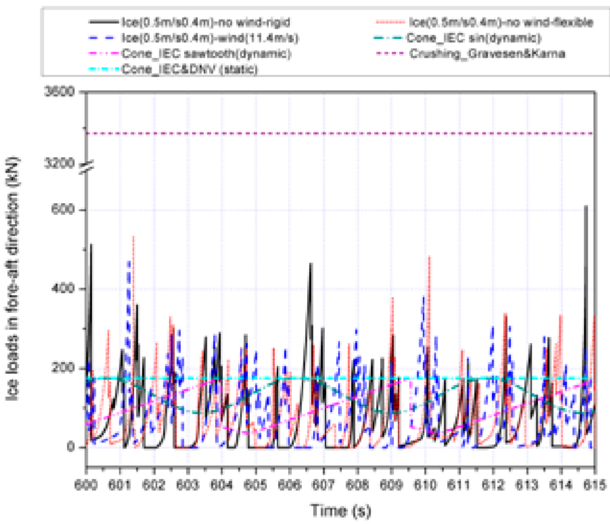


Figure 41: *Time series of the ice loads in the fore-aft direction of a monopole wind turbine based on the numerical analysis and various design standards (ice thickness of 0.4 m and drifting speed of 0.5 m/s).*

Related publications:

- **Shi, Wei; Tan, Xiang; Gao, Zhen; Moan, Torgeir.** Comparative study on dynamic response of offshore wind turbine with monopile and spar considering ice-structure interaction. RAVE Offshore Wind R&D Conference 2015; 2015-10-13 - 2015-10-15
- **Shi, Wei; Tan, Xiang; Gao, Zhen; Moan, Torgeir.** Numerical study of ice-induced loads and responses of a monopile-type offshore wind turbine in parked and operating conditions. Cold Regions Science and Technology 2016 ;Volume 123. p. 121-139

Numerical modelling and dynamic analysis of floating vertical axis wind turbines

Project manager: Professor Torgeir Moan
Research associates: Professor Zhen Gao, Dr Kai Wang, Dr Helge Aagaard Madsen
PhD candidate: Zhengshun Cheng
Project collaborators: NTNU AMOS, MARE-WINT, CeSOS
Project webpage: www.marewint.eu

The new MAterials and REliability in offshore WINd Turbines technology project, MARE WINT, is a Marie Curie Initial Training Network grantee within the EU 7th Framework Programme.

By using floating vertical axis wind turbines (VAWTs), the cost of energy can potentially be reduced by 20% compared with floating horizontal axis wind turbines (HAWTs). This research aims to develop a fully coupled method for modelling and analysis of floating VAWTs and to study the dynamic response characteristics of floating VAWTs with different floaters and rotors.

An aerodynamic code has been developed based on the Actuator Cylinder (AC) flow method and integrated with the SIMO-RIFLEX tool. It can be used for coupled analysis of floating VAWTs, accounting for the turbulent and dynamic inflow, aerodynamics, hydrodynamics, structural dynamics and control system dynamics. It has been verified by comparison with experiments and other computer codes.

A comparative study of three floating VAWTs (shown in Figure 42) with a two-bladed 5MW Darrieus rotor revealed a significant response at the 2P frequency (two times the rotor frequency). It was found that the compliant catenary mooring system can help in mitigating the 2P effect. A comparative study of a spar floating HAWT and VAWT indicates that, owing to different aerodynamic load characteristics and control strategies, the current design of the floating VAWT leads to both larger mean and dynamic responses in the tower and mooring lines and requires further improvements.

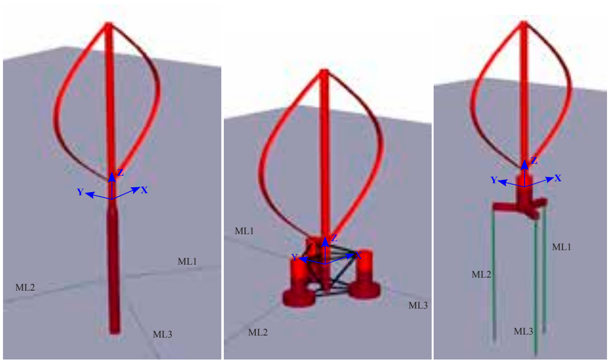


Figure 42: *Three floating VAWT concepts: (from left) spar, semi-submersible and TLP.*

Related publications:

- **Cheng, Zhengshun; Wang, Kai; Gao, Zhen; Moan, Torgeir.** Dynamic Response Analysis of Three Floating Wind Turbine Concepts with a Two-Bladed Darrieus Rotor. Journal of Ocean and Wind Energy 2015 ;Volume 2.(4) p. 213-222
- **Cheng, Zhengshun; Wang, Kai; Gao, Zhen; Moan, Torgeir.** Dynamic Modelling and Analysis of Three Floating Wind Turbine Concepts with Vertical Axis Rotor. I: Proceedings of the twenty-fifth International Ocean and Polar Engineering Conference - ISOPE 2015. International Society of Offshore & Polar Engineers 2015 ISBN 978-1-880653-89-0. p. 415-423
- **Wang, Kai; Cheng, Zhengshun; Moan, Torgeir; Hansen, Martin Otto Laver.** Effect of difference-frequency forces on the dynamics of a semi-submersible type FVAWT in misaligned wave-wind condition. I: Proceedings of the twenty-fifth International Ocean and Polar Engineering Conference - ISOPE 2015. International Society of Offshore & Polar Engineers 2015 ISBN 978-1-880653-89-0. p. 517-524

Probability estimation of trawler board hooking of pipelines

Project manager: Professor Torgeir Moan
Research associates: Professor Svein Sævik
PhD candidates: Xiaopeng Wu, Dr Vegard Longva
Project collaborators: NTNU AMOS, CeSOS

In the assessment of the safety of oil and gas pipelines, the possible effect of trawling gear that become firmly "stuck" to the pipeline (hooking) must be considered. These events rarely occur but can have detrimental consequences. To estimate the risk related to a hooking event, the probability of hooking must be quantified. However, there is no existing method to estimate this hooking probability. This work addresses this issue.

An approach is proposed to quantify the trawl board hooking probability using advanced numerical models to estimate the motions of the trawling gear, pipeline lay-out and statistical data on the trawling operation. The criterion defining a hooking event is established based on observations in model tests. Numerical simulations using the SIMLA code were compared with model test results, and reasonable agreement was obtained. The criteria link the pipeline data to the fishing activities data, enabling the quantification of hooking probability. Data for the EUROPIPE II pipeline section in the Norwegian sector were used as a case study.

Figure 43: *Model test video snapshot of hooking event.*

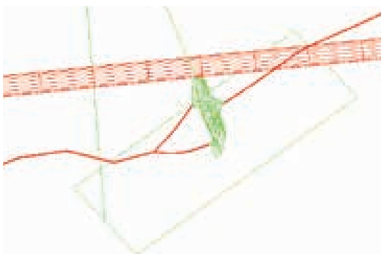


Figure 44: *Simulation snapshot of hooking event.*

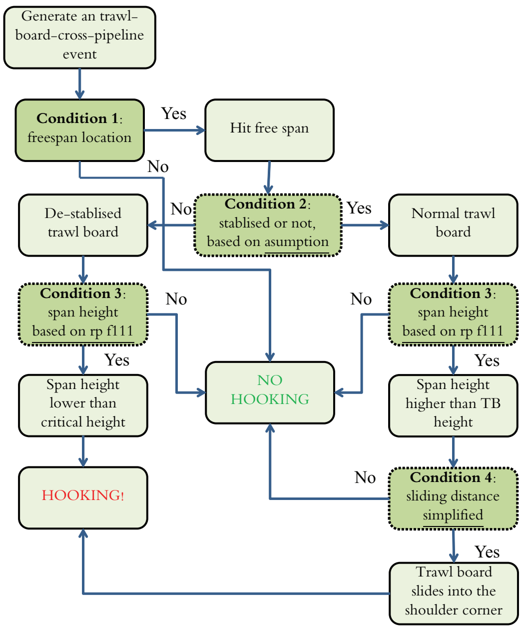


Figure 45: *Event chain of trawl board hooking events with simplified conditions.*

Related publication:

- **Wu, Xiaopeng; Longva, Vegard; Sævik, Svein; Moan, Torgeir.** A Simplified Approach to Estimate the Probability of Otter Board Hooking at Pipelines. Journal of Offshore Mechanics and Arctic Engineering-Transactions of The Asme 2015 ;Volume 137.(6)

Sensor fusion and collision avoidance for autonomous surface vehicles (Autosea)

Project manager: Associate prof. Edmund Førland Brekke
Research associates: Dr Morten Breivik, professors Tor Arne Johansen, Kristin Y. Pettersen and Thor I. Fossen, Dr Andrea Cristofaro
PhD candidates: Andreas Flåten, Bjørn-Olav Holtung Eriksen, Erik Wilthil
Project collaborators: NTNU AMOS, DNV GL, Kongsberg Maritime, Maritime Robotics
Project webpage: https://www.ntnu.edu/amos/autosea

The Autosea project, which is funded by the Research Council of Norway via MAROFF, will develop collision avoidance methods for autonomous ships. These methods shall comply with the traffic rules at sea, known as COLREGS. Furthermore, the methods will utilize information from a variety of sensors and data sources, including radar, GPS, AIS, inertial sensors and charts. Thus, sensor fusion plays a central role. The autonomous ship must detect and track other ships in its vicinity, anticipate their manoeuvres, and plan its own route to avoid collisions and satisfy COLREGS. Although the focus of this project is on autonomous vessels, the results will also be applicable to decision support systems for manned ships and to other unmanned vehicles such as driverless cars.

While investigating several established approaches to collision avoidance, a novel and very general methodology for collision avoidance based on model predictive control (MPC) has been developed. In this method, one out of finitely many control actions is chosen by evaluating the corresponding scenarios and minimizing the hazard. In parallel, experiments at sea were conducted during the last weeks of 2015 to gather data from radar and AIS to be used in the development of sensor fusion methods.

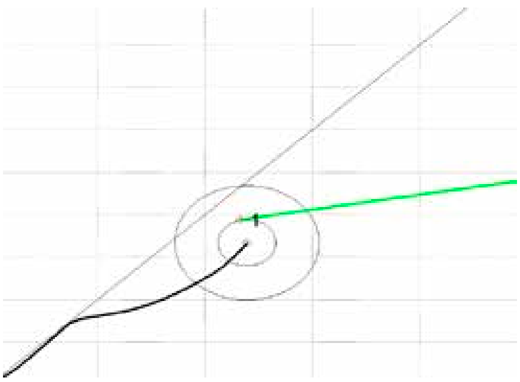


Figure 46: *Ownship (black) avoids target ship (green). In this case, ownship has the responsibility to stay away and must therefore manoeuver so that target ship is allowed to pass in front.*

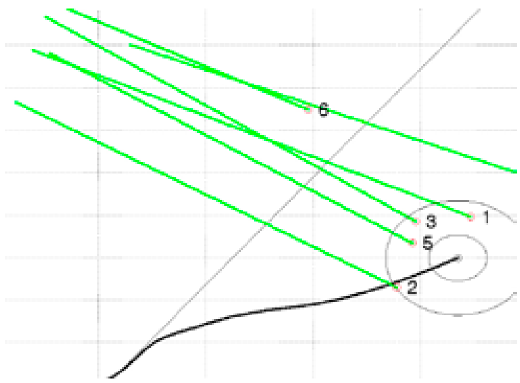


Figure 47: *In this case, ownship has the right to stay on. Ownship chooses to stay on and passes in front of most of the target ships, instead of reducing speed because staying on leads to less deviation from the pre-planned route and safety margins are considered large enough to stay on safely.*

Snake locomotion in challenging environments

Project manager: Professor Kristin Y. Pettersen
Research associates: Professors Odd Faltinsen, Jan Tommy Gravdahl, Marilena Greco and Asgeir J. Sørensen, associate professor Øyvind Stavdahl, Aksel A. Transeth, Dr Christian Holden, Dr Pål Liljebäck
PhD candidates: Eleni Kelasidi, Ehsan Rezapour
Project collaborators: NTNU AMOS, SINTEF ICT

SINTEF

The project Snake Locomotion in Challenging Environments is funded by the Research Council of Norway through FRINATEK. The project goal is to develop new methods and tools for snake robot locomotion in challenging environments on land and underwater.

The FRINATEK project *Snake Locomotion in Challenging Environments* has investigated and developed new research results and technology for snake locomotion in challenging environments from 2011–2015.

Inspired by biological snakes, external objects and irregularities are considered beneficial to the snake robot because they represent push-points around which the robot can curl to push its body forward. Body shape adaption to the environment is a key ingredient of snake locomotion, and it is what gives snake robots the potential to move and operate in environments where conventional wheeled, tracked and legged robots are likely to fail. To fully embrace this unique feature of snake locomotion, the SLICE project has investigated and developed research results that create synergies between environment interaction and forward propulsion of snake robots. Furthermore, the project has developed new research results for the control of snake robots moving both on ground and in water.

For snake robots, there exists no simple and intuitive mapping between actuators and locomotion. In particular, a snake robot has no motors or thrusters creating linear forces such as mobile robots and marine vehicles. The thrust on the robot is rather produced by the coordinated efforts of the whole articulated body of this mechanism. Moreover, the mapping from changes in body shape to the resulting motion of a snake robot is highly complex, so it is not intuitive to predict how the overall position and orientation of the robot will change as a function of how the body shape changes over time. Consequently, a snake robot has a layer of control complexity absent in more conventional mobile robots and marine vehicles, and a significant control effort is required by the whole body shape of the snake robot for it to be propelled according to a specified motion command.

To experimentally verify project results, the project has developed a novel snake robot prototype with force/torque sensors for sensing obstacles in the environment. The robot can also swim underwater owing to its water-tight design.

Media coverage:
- Robotnor.no, Our snake robots in the media: http://robotnor.no/our-snake-robots-in-the-media

Related publications:

- **Liljeback, Pål; Pettersen, Kristin Ytterstad; Stavdahl, Øyvind; Gravdahl, Jan Tommy.** Snake Robots - Modelling, Mechatronics, and Control. Springer 2013 (ISBN 978-1-4471-2995-0) 317 p. Advances in Industrial Control
- **Kelasidi, Eleni; Liljebäck, Pål; Pettersen, Kristin Ytterstad; Gravdahl, Jan Tommy.** Biologically Inspired Swimming Snake Robots: Modeling, Control and Experimental Investigation. To appear in IEEE Robotics and Automation Magazine, 2016
- **Mohammadi, Alireza; Rezapour, Ehsan; Maggiore, Manfredi; Pettersen, Kristin Ytterstad.** Maneuvering Control of Planar Snake Robots Using Virtual Holonomic Constraints. To appear in IEEE Transactions on Control Systems Technology, 2016

• **Kelasidi, Eleni; Liljebäck, Pål; Pettersen, Kristin Ytterstad; Gravdahl, Jan Tommy.** Experimental investigation of efficient locomotion of underwater snake robots for lateral undulation and eel-like motion patterns. Robotics and Biomimetics 2015 ;Volume 2.(8)

Figure 48: *Mamba – a novel snake robot prototype.*

Structural design of reliable offshore aquaculture structures

Project manager: Professor Jørgen Amdahl
Research associate: Dr David Kristiansen
PhD candidate: Pål Takle Bore
Project collaborators: NTNU AMOS, SFI EXPOSED and partners
Project webpage: http://exposedaquaculture.no/en/research-areas

EXPOSED

The work will aim towards the development of knowledge-based technical requirements for the main components of fish farms for exposed locations, focusing on HSE, operational aspects and prevention of fish escapes. The development of rational design requirements for aquaculture structures will be based on simulations of the governing physical phenomena, with emphasis on analyses of hydrodynamic loads, load effects and structural resistance. The activities include the following:

- Development of knowledge-based design criteria for moored net-cage systems;
- Analysis of fatigue, ultimate strength and accidental limit state conditions;
- Development of simplified design-oriented load cases (e.g., static load cases) that are calibrated against results from fundamental numerical simulations.

In his master thesis work, Pål Takle Bore (together with P.A Fossan) analysed Ocean Framing´s steel cage concept for deep and exposed waters (see Figure 49).

The fish farm, which has a diameter of 110 m and can hold up eight times as much fish as standard fish farms, is fixed to the seabed with eight catenary mooring lines. The small water-plane area and slender braces make it transparent to wave forces, thus yielding moderate forces and motions. It was designed for a significant wave height of 5 m. Although the design of standard fish farms is often based on experience and simplified methods, the complexity and assets of the present facility call for design by advanced methods similar to those adopted for offshore structures. In the master thesis work, time domain stochastic analysis of the response in extreme sea states,

Figure 49: *Ocean Farming facility.*

with durations of three hours, was conducted to determine the utilization with respect to ultimate limit states of the steel cage and mooring lines (Figure 50).

Figure 50: *Simulation of fish farm response in irregular seas.*

In addition, fatigue analyses were conducted for selected hot spot regions, as shown in Figure 51, for a representative number of long-term sea states.

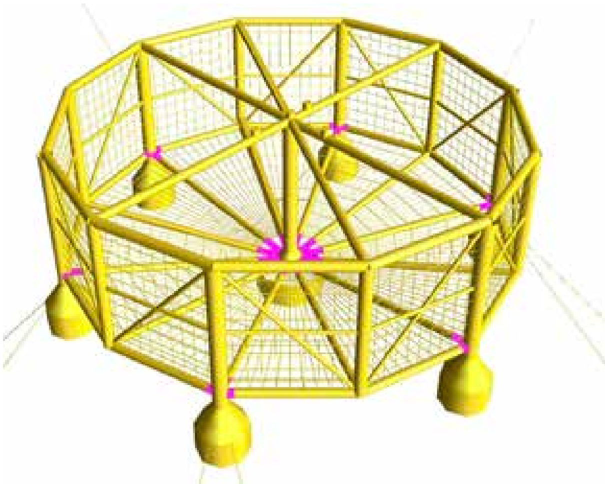


Figure 51: *Joints checked for fatigue.*

In this project, these analyses will be revisited with updated and more precise information of the design parameters and stress concentration factors for hot spot regions.

PHOTO GALLERY

Key Scientists

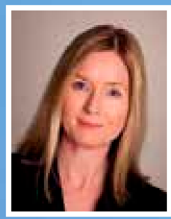

Prof. Asgeir J. Sørensen, Director


Prof. Thor I. Fossen, Co-director


Prof. Jørgen Amdahl

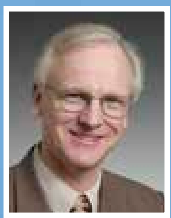

Prof. Marilena Greco


Prof. Tor Arne Johansen

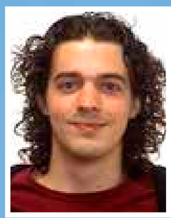

Prof. Kristin Y. Pettersen

Adjunct professors and adjunct associate professors


Adj. ass. prof. Erin E. Bachynski

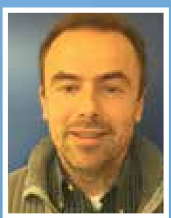

Prof. Mogens Blanke


Adj. prof. Arne Fredheim

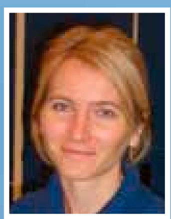

Adj. ass. prof. Martin Føre

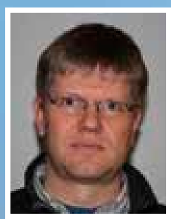

Adj. ass. prof. Vahid Hassani


Prof. Jørgen Juncher Jensen

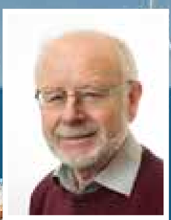

Adj. prof. Claudio Lugni

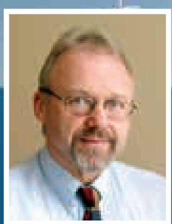

Adj. ass. prof. Ulrik Dam Nielsen


Adj. ass. prof. Nadezda Sokolova


Adj. ass. prof. Rune Storvold

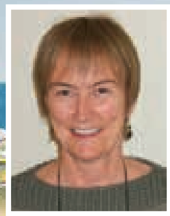
Senior scientific advisers


Prof. Odd M. Faltinsen


Prof. Torgeir Moan

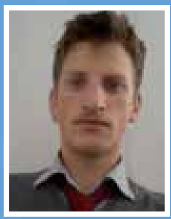
Administration


Annika Bremvåg

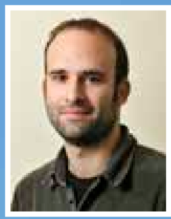

Sigrid Bakken Wold

Post-docs


Dr Konstantin Amelin


Dr Andrea Cristofaro


Dr Ekaterina Kim


Dr Anastasios Lekkas

Affiliated scientists


Ass. prof. Jo Arve Alfredsen

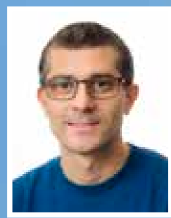

Dr Morten Breivik


Ass. prof. Edmund Brekke


Prof. Zhen Gao


Prof. Lars S. Imsland


Prof. Geir Johnsen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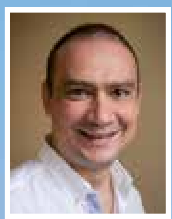
Dr Pål Liljebäck


Prof. Martin Ludvigsen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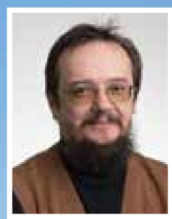
Prof. Ingrid Schjølberg


Prof. Roger Skjetne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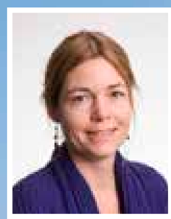
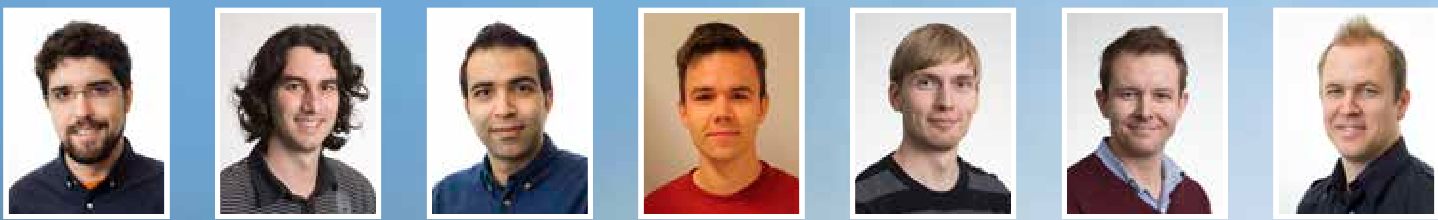

Prof. Ingrid B. Utne

PhD candidates

Inga Aamodt | Wilson G. Acero | Anders Albert | Sigurd M. Albrektsen | Leif Erik Andersson | Dennis Belleter | Pål T. Bore

Daniele Borri | Kasper T. Borup | Astrid H. Brodtkorb | Torleiv H. Bryne | Torstein I. Bø | Mauro Candeloro | Zhengshun Cheng

Seong-Pil Cho | Krzysztof Cisek | Andreas Reason Dahl | Ole A. Eidsvik | Bjørn-Olav Holtung Eriksen | Daniel de A. Fernandes | Andreas Lindahl Flåten



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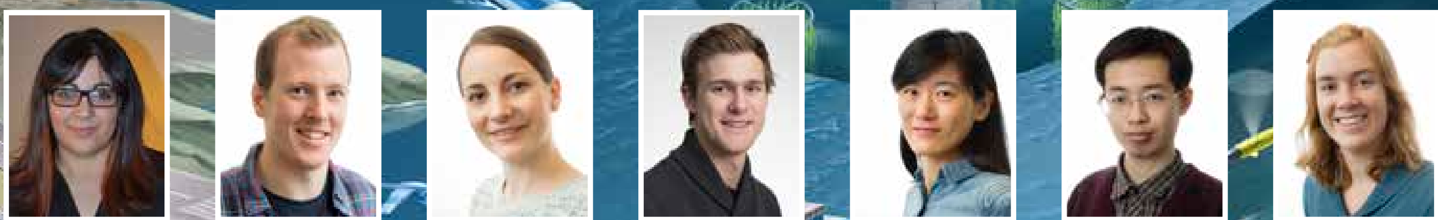
Jeevith Hegde | Håkon Hagen Helgesen | Eirik Hexeberg Henriksen | Hans-Martin Heyn | Jan-Tore H. Horn | Erlend K. Jørgensen | Ulrik Jørgensen



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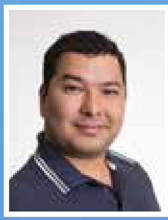
Marianne Merz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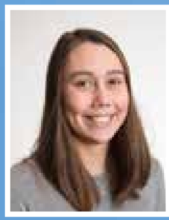
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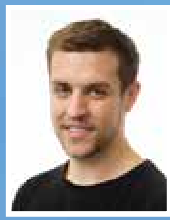
Albert Sans Muntadas


Woongshik Nam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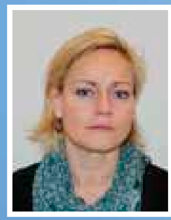
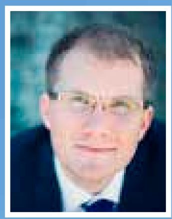

Ingunn Nilssen


Petter Norgren


Stein M. Nornes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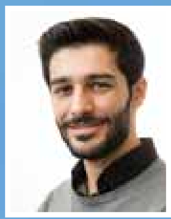
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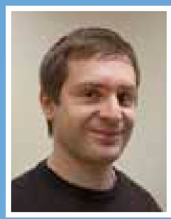
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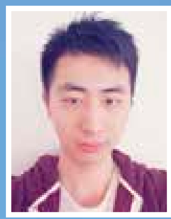
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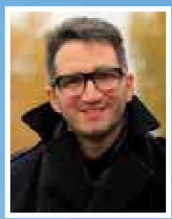
Christopher D. Rodin


Robert Rogne


Børge Rokseth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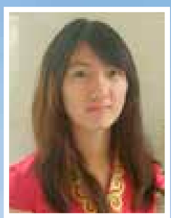
Thomas Sauder


Yugao Shen


Mohd A. Siddiqui


Espen Skjong


Emil Smilden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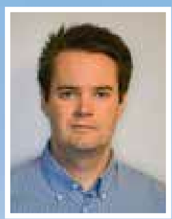
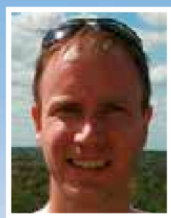

Martin Storheim

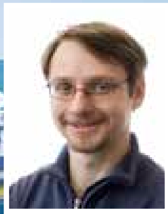

Bård B. Stovner


Ida M. Strand


Jørgen Sverdrup-Thygeson


Kim L. Sørensen


Mikkel E. N. Sørensen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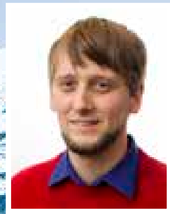
Svenn A. Tutturen Værnø


Stefan A. Vilsen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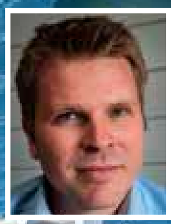
Martin S. Wiig


Erik F. Wilthil


Zhaolong Yu


Yuna Zhao


Artur Zolich


Øyvind Ødegård

LABORATORY HIGHLIGHTS AND RESEARCH CAMPAIGNS

Highlights of the Applied Underwater Vehicle laboratory (AUR-lab)

The lab's webpage: https://www.ntnu.edu/aur-lab

The AUR-Lab is an interdisciplinary lab where engineering science, natural science and archaeology join forces to explore the ocean space. Technology providers and users work together with underwater vehicles and sensors to improve our understanding of the ocean and to further develop the necessary robotic tools. The lab is a common effort between the IVT, IME, SVT faculties and the University Museum to serve all of NTNU. The lab runs several ROVs and one REMUS 100 AUV equipped with advanced scientific and navigation instruments. The Department of Marine Technology hosts the lab, along with the facilities at the Trondheim Biological station, provided by the Department of Biology. Arctic research, autonomy development and marine mineral investigation are some of the areas of research of the AUR-Lab in 2015.

2015 began with course work and research on zooplankton migration and robotics in the polar night at 79° North in Ny-Ålesund in a joint operation with UNIS and UiT. AUV REMUS was sent into the polar night searching for acoustical signatures of marine life. In August, we headed for Jan Mayen to map Lake Nord-Lagunen for geological features in collaboration with NGU. A surprising discovery of the remains of a modern settlement was made. Read the full story at the links below. Only a few weeks later, a new adventure was underway in Svalbard. Together with UNIS, the AUV REMUS was deployed in Trygghamna and located the wreck of the whaling ship Figaro, which sank in 1905. It is known as the northernmost shipwreck identified.

Back in Trondheim, engineering research included collaborative vehicles, such as having an unmanned surface vessel from Maritime Robotics AS autonomously track and tender our AUV during the mission. To open for more advanced operations in the future, AUV docking was investigated, and the USBL system was adapted to the AUV to allow the vehicle to track docking stations and navigate its way home for battery charging and data retrieval.

The AUR-Lab has implemented a method for developing underwater photogrammetry models using a stereo camera rig that has been configured and installed on our ROVs. The wreck of the tug Herkules, located at approximately sixty meters depth, close to Munkholmen, was used as a test site to refine the method to increase the accuracy of the photogrammetric models.

For ROV control, an integration of the Oculus Rift system was demonstrated, both for vehicle control and for 3D telepresence.

In 2015, we mapped the wreck of a British Halifax bomber aircraft using photogrammetry, hyperspectral imaging and video. The plane was shot down during an Allied bombing raid of the German cruiser Tirpitz in April 1942. A detailed photogrammetry model was established to document the current state of the wreck site and provide central information about the crash.

The Discovery Channel visited NTNU and the AUR-Lab during one of our campaigns to map the plane. Working on the shipwreck requires special attention with respect the two British plane crew members who perished during the crash in 1942.

During 2015, the AUR-Lab also set a new internal depth record, running a hyperspectral imager to 4200 meters depth on a European JPIO cruise onboard the German research vessel RV Sonne in the Pacific. The target for the investigation was seabed nodules containing high mineral concentrations.

Figure 52 *(Martin Ludvigsen, NTNU): AUV REMUS outside UNIS in Longyearbyen.*

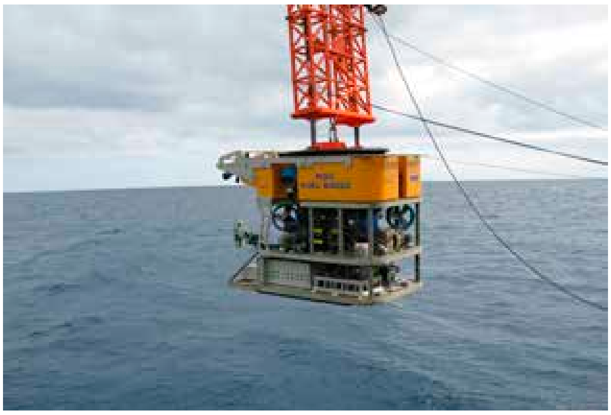


Figure 53 *(Stein M. Nornes, NTNU): ROV Kiel6000 during launch in the Pacific.*

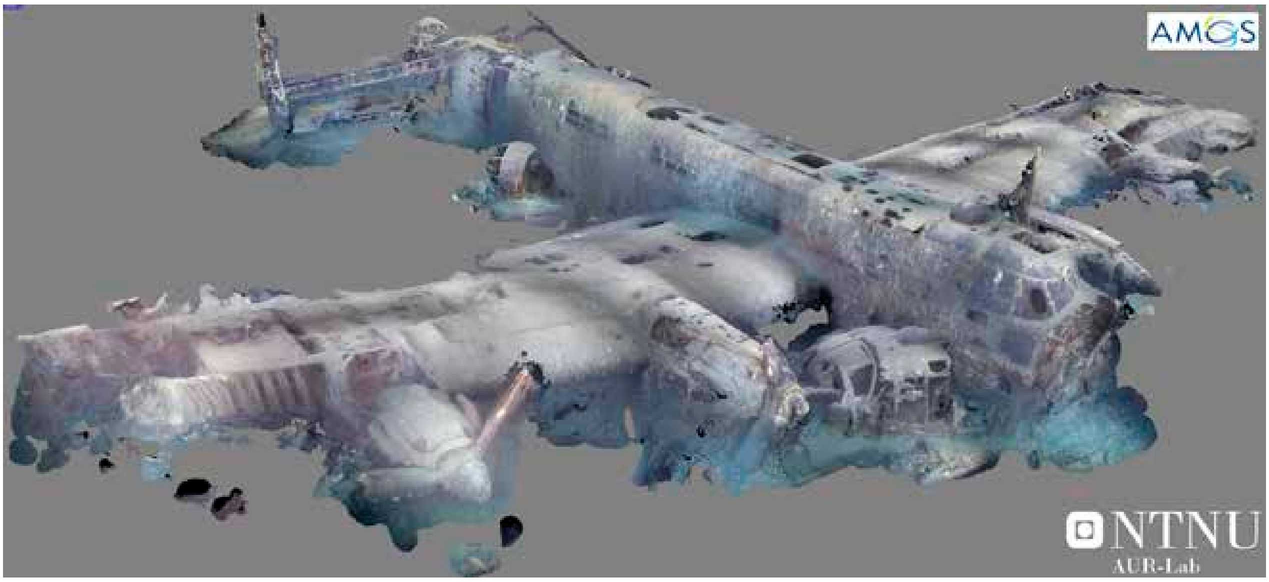


Figure 54 *(Stein M. Nornes, NTNU): Photogrammetry model of the wreck of the Halifax bomber aircraft.*

Figure 55 *(AUR-lab): ROV SF 30k on the wreck of the tug Hercules, close to Munkholmen.*

Figure 56 *Photogrammetry model of the Herkules wreck close to Munkholmen.*

Figure 57 *(Ingrid Myrnes Hansen, NTNU): The ROV SF 30k operated using the virtual reality system Oculus Rift.*

Media coverage:

- Forskning.no, Jan Mayen-forskere fant rester av amerikansk krigsbase, 6 January 2016: http://forskning.no/2016/01/jan-mayen-forskere-fant-amerikansk-krigsbase
- Forskning.no, Vil avdekke Jan Mayens hemmeligheter, 5 January 2016: http://forskning.no/2016/01/vil-avdekke-jan-mayens-hemmeligheter
- Schrödingers katt (TV), Klart for dyphavsgruver, NRK, 19 November 2015: https://tv.nrk.no/serie/schrodingers-katt/DMPV73002015/19-11-2015#t=43s
- Daily Planet (TV), Underwater vehicles, Discovery channel, 2 November 2015
- Forskning.no, Slik skal Kon-Tiki 2 utfordre Heyerdahls teorier, 27 October 2015: http://forskning.no/havforskning-samfunnsgeografi/2015/10/kon-tiki2-i-heyerdals-kjolvann
- NRK.no, Forskarane har aldri funne skipsvrak så langt nord før no: – Dette er berre starten, 19 September 2015: http://www.nrk.no/troms/har-funne-det-nordlegaste-skipsvrak-i-verda_-_-dette-er-berre-starten-1.12560855
- Adressa.no, TV-kanalen Discovery viser krigsfly i Trondheimsfjorden til 8 millioner seere, 2 July 2015: http://www.adressa.no/nyheter/trondheim/article11266093.ece
- NRK.no, Fant koraller på bomber i Trondheimsfjorden, 2 January 2015: http://www.nrk.no/trondelag/fant-koraller-pa-bomber-i-trondheimsfjorden-1.12128831

Highlights of the Unmanned Aerial Vehicle laboratory (UAV-lab)

The lab's webpage: http://www.itk.ntnu.no/english/lab/unmanned

The unmanned aerial vehicles (UAV) laboratory is a test facility for NTNU's research on unmanned aerial systems (UAS). We are using Agdenes airfield as a primary test field located approximately 90 km southwest of Trondheim. In 2015, we also operated UAVs from Eggemoen, Ørland, Ny-Ålesund, Oppdal, Fairbanks (Alaska) and Azores (Portugal). Various payload system have been integrated and used in the Penguin B and X8 fixed-wing UAV's in addition to several multi-rotor platforms. The primary sensors in use have been thermal cameras, daylight cameras, a hyperspectral camera, and an advanced navigation sensor suite. Research has also been concentrated on coordinated control of multiple UAVs for high-precision multibody operations.

Figure 58: *X8 UAV landing at Ny-Ålesund, Svalbard.*

Extensive work has been invested into a new flexible and powerful system architecture based on the Pixhawk open source autopilot:

Zolich, Artur Piotr; Johansen, Tor Arne; Cisek, Krzysztof; Klausen, Kristian. Unmanned Aerial System Architecture for Maritime Missions. Design & Hardware Description. Proceedings of the IEEE 2015

This architecture has been applied in numerous systems system as a lightweight gimbal thermal camera payload system for autonomous object detection and tracking:

Leira, Frederik Stendahl; Trnka, Kenan; Fossen, Thor I.; Johansen, Tor Arne. A Light-Weight Thermal Camera Payload with Georeferencing Capabilities for Small Fixed-Wing UAVs. I: 2015 International Conference on Unmanned Aircraft Systems (ICUAS). IEEE conference proceedings 2015 ISBN 978-1-4799-6009-5. p. 485-494

Navigation research has focused on integrated inertial navigation aided by cameras and RTK GPS:

Hosen, Jesper; Helgesen, Håkon Hagen; Fusini, Lorenzo; Fossen, Thor I.; Johansen, Tor Arne. A Vision-aided Nonlinear Observer for Fixed-wing UAV Navigation. AIAA Guidance, Navigation, and Control Conference, San Diego, 2016

Hansen, Jakob Mahler; Fossen, Thor I.; Johansen, Tor Arne. Nonlinear Observer for INS Aided by Time-Delayed GNSS Measurements - Implementation and UAV Experiments. I: 2015 International Conference on Unmanned Aircraft Systems (ICUAS). IEEE conference proceedings 2015 ISBN 978-1-4799-6009-5. p. 157-166

Methods for estimation of flight performance parameters and wind velocity have been developed and tested. These are critically important for autonomous landing and operation in harsh weather conditions:

Johansen, Tor Arne; Cristofaro, Andrea; Sørensen, Kim; Hansen, Jakob Mahler; Fossen, Thor I. On Estimation of Wind Velocity, Angle-of-Attack and Sideslip Angle of small UAVs using Standard Sensors. I: 2015 International Conference on Unmanned Aircraft Systems (ICUAS). IEEE conference proceedings 2015 ISBN 978-1-4799-6009-5. p. 510-519

Highlights of the experiments at CNR-INSEAN sloshing lab

The lab's webpage: http://www.insean.cnr.it/en/content/sloshing-lab

The lab consists of three different facilities: a single degree of freedom mechanical system, designed to enforce pure-sway sinusoidal motion to a 2D and 3D prismatic sloshing tank; a six-degree of freedom mechanical system 'Hexapod', for sloshing experiments of 2D and 3D tanks; and a 2D water-entry and exit facility. In 2015, the 'Hexapod' system was used to perform experiments on water-oil-boom interactions for the PhD studies of Daniele Borri, with Prof. Marilena Greco as the main supervisor. This PhD research focuses on the hydrodynamics of oil spills. Oil booms represent a valid solution for spilled oil clean-up, but their performance has a limitation in sufficiently strong currents and high sea waves. Comparison of different oil boom designs in terms of boom failure is the purpose of the present experiments, which are the continuation of a previous experimental campaign in 2014. Boom failure means that part of the oil goes beneath the boom and is no longer contained.

The model tests were performed inside a tank 3 m long, 0.6 m high and 0.1 m wide, mounted on the 'Hexapod' platform. The experimental setup is shown in Figure 59 and was designed for 2D flow conditions in the tank. However, clear 3D features were recorded when instabilities and boom failures occurred.

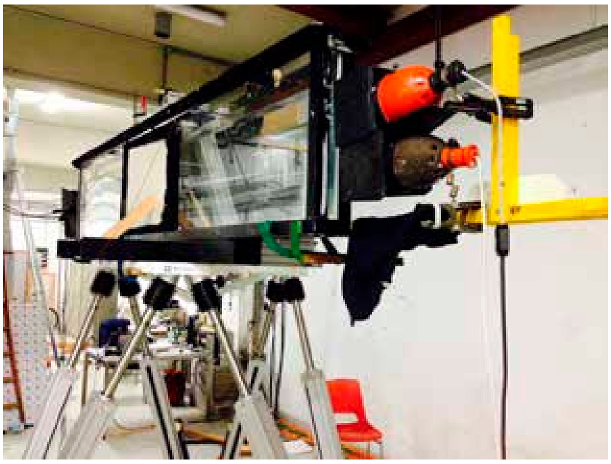


Figure 59: *Experimental setup for oil-boom studies.*

Three boom geometries were tested (see Figure 60): (A) a basic configuration, geometrically reproducing a real boom with an outer floater and a skirt; (B) a variant, with an end plate added on the bottom of the basic geometry and (C) a variant, with a smooth envelope added to the basic geometry, enclosing half of the floater and the skirt.

The models were built to a 1:6 scale and realized in rigid expanded polyurethane. Alternatives B and C were examined to reduce the strength of the vortex-shedding phenomenon occurring at the bottom of basic boom A, partially responsible for instabilities at the water–oil interface or oil accumulation near the boom. Both phenomena can lead to entrainment of oil drops in water and possibly to boom failure. The experimental analysis is ongoing and showed a greater effectiveness of the end plate in avoiding boom failure.

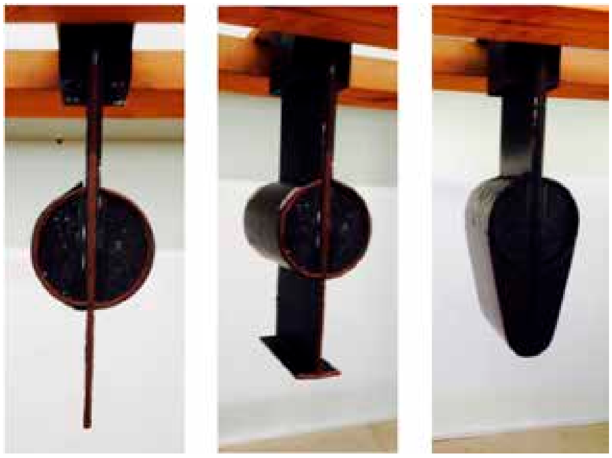


Figure 60: *Boom configurations. Left: A; centre: B; right: C.*

Research campaign: Rapid Environment Picture 2015 (REP'15)

Supervisors: Professors Tor Arne Johansen and Thor I. Fossen
PhD candidates: Krzysztof Cisek, João Fortuna, Frederik S. Leira

Continuing from previous years, NTNU AMOS was participating in the Rapid Environment Picture 2015 (REP-15) exercise organized by University of Porto and the Marinha Portuguesa.

The primary goal of this edition of REP was to demonstrate coordinated strategies for aerial and underwater robotic vehicles, in the context of specific pure scientific objectives. These vary from habitat mapping of the southern coast of Pico Island in the Azores, to observing and tracking cetaceans in open waters south of Pico near the São Mataeus bank, to mapping and characterizing the upper water column near shallow hydro-thermal vents near Ponta de Espalamaca just north of Horta on Faial Island.

By bringing autonomous vehicles, a number of goals were achieved:

- to test software algorithms and operational concepts that are novel and to do so in real-world surroundings
- to train a new generation of engineers and scientists in the use of robotic elements for inter-disciplinary science
- to train and collaborate with a range of scientific and technical personnel from different perspectives in ocean and environmental science and engineering

At REP-2015, there was a mix of students, faculty and researchers from FEUP (Faculty of Eng. Univ of Porto), NTNU (Norwegian Univ. of Science and Technology), DOP (Dept. of Oceanography, Azores), NUWC (US Naval Undersea Warfare Center), IH (Instituto Hidrografico) and CMRE (Center for Maritime Research & Experimentation). The primary role of NTNU AMOS was the operation of several X8 UAVs carrying payload equipped with thermal and hyperspectral cameras. The UAVs were launched from a catapult and recovered in a landing net, using the Navy/IH research vessel NRP Almirante Gago Coutinho as the operational base. NTNU's operational team consisted of João Fortuna, Frederik Leira, Lars Semb and Krzysztof Cisek, and the experiments were coordinated by Professors João Sousa and Kanna Rajan at University of Porto in collaboration with Professor Tor Arne Johansen at NTNU.

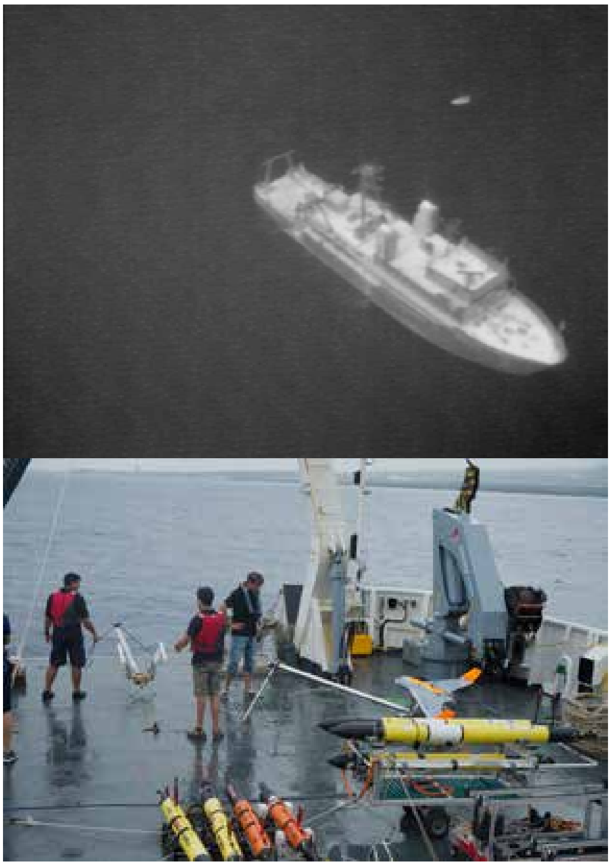


Figure 61: *The teams from NTNU and University of Porto are preparing to launch several UAVs and AUVs in a coordinated operation from the navy vessel.*

Research campaign: Oden Arctic technology research cruise 2015

Supervisor: Professor Roger Skjetne
PhD candidates: Øivind Kåre Kjerstad, Qin Zhang, Hans-Martin Heyn

Good synergy has been established between the research centres of CoE NTNU AMOS and CRI SAMCoT (Sustainable Arctic Marine and Coastal Technology) through common research activities and researchers. In NTNU AMOS, a broad scope of the research activities relate to technology for mobile sensor platforms and autonomous systems for marine operations, for instance, applied to dynamic positioning (DP) and position mooring (PM) offshore operations. The research of SAMCoT, on the other hand, focuses on the understanding and modelling of the physical Arctic environment, methods for verification of structural design and Arctic offshore operations through the development of numerical tools, and field campaigns for real observations and data collection. This collaboration is exemplified by the Oden Arctic Technology Research Cruise (OATRC'15).

In September-October 2015, researchers from NTNU AMOS and SAMCoT participated on the OATRC'15 expedition, an NTNU field campaign sponsored by ExxonMobil. Two Swedish icebreakers, Oden and Frej, set out from Longyearbyen on September 18th to an ice field at 82.5°N, 16°E. The objective of this cruise was to test ice management tactics with two icebreakers, examine the technology and methods for measuring and monitoring ice parameters, and collect data.

The two icebreakers were instrumented with camera systems and numerous sensors to observe icebreaking

Figure 62 *(Per Frejvall): Oden Arctic Technology Research Cruise 2015. Scientific crew on icebreaker Oden.*

phenomena and acquire important sea-ice data. A 360-degree camera system and several special purpose cameras were used to capture images from the surrounding ice field throughout the expedition.

Figure 63 *(Sveinung Løset, NTNU): Professor Roger Skjetne mounting a forward-looking 180-degree camera.*

Four IMUs were also placed on each ship for measuring ice-induced accelerations in the hull.

In addition, the marine radar was used to capture images for ice-field surveillance, an ice-penetrating radar using electromagnetic antennas measured ice thickness, CTD samples were frequently collected, and many more external and ship sensors were used. Figure 65 shows the real-time acquisition system installed to ensure that time-synchronized data were stored with correct time-stamps.

Figure 64 *(Roger Skjetne, NTNU): The Frej icebreaker and the helicopter seen from the bridge of Oden.*

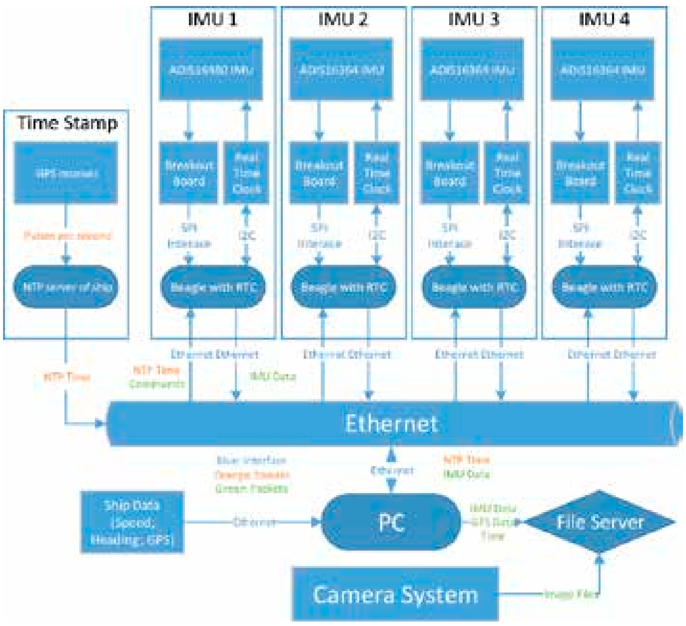


Figure 65 *(Hans-Martin Heyn, NTNU): Time-synchronized data acquisition system.*

The icebreakers conducted ice management tactics trials almost every day, i.e., the two icebreakers were collaborating on battling the drifting sea-ice cover to reduce ice loads on a virtual "protected vessel", which, for instance, would be a scientific vessel on DP or a drillship on PM. Every day there were manned helicopter flights to document the ice field conditions with high altitude photos. The company Nordic Unmanned was also onboard to test their unmanned aerial vehicles for use in ice management.

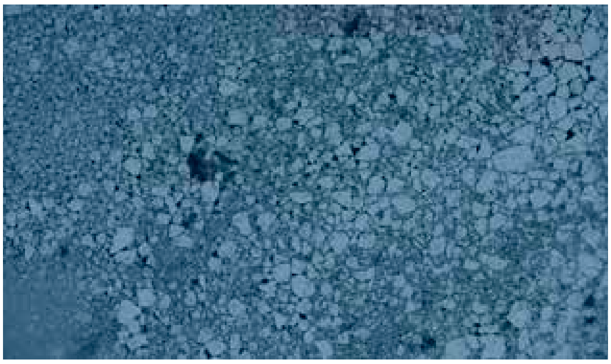


Figure 66 *(NTNU): Helicopter image from the marginal ice zone.*

From the manned helicopter images, we obtained the images in Figure 66. An important parameter in such images is the floe size distribution. We developed algorithms through the PhD study of Qin Zhang to identify individual ice floes in such images. It is then easy to extract information, such as ice concentration, floe size distribution, floe positions, characteristic shapes, etc. An example of the output from this algorithm is shown in Figure 67.

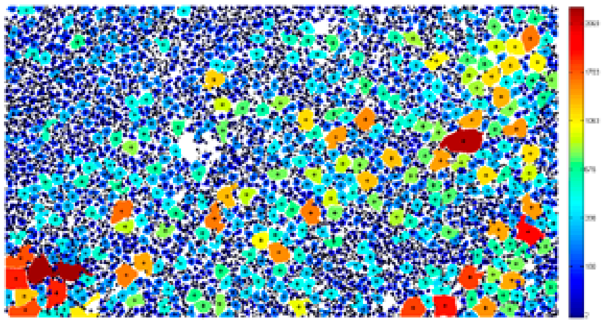


Figure 67: *Identified ice floes after image processing.*

After two weeks in the ice, away from infrastructure, such as internet or telephone services, we returned and disembarked in Longyearbyen on October 2nd. We returned from the trip with considerable experience on how to conduct operations in heavy Arctic sea-ice and cold weather, and with several tera-bytes of data to be analyzed in years to come. One of the last highlights of the trip, before entering and leaving the marginal ice zone, was a close encounter with a polar bear, one evening around dinner-time. He probably smelled the bacon from far away.

Figure 68 *(Roger Skjetne, NTNU): Close encounter with a polar bear, just by the ship side.*

Related publications:

- **Zhang, Qin; Skjetne, Roger**. Image Processing for Identification of Sea-Ice Floes and the Floe Size Distributions. IEEE Transactions on Geoscience and Remote Sensing 2015 ;Volume 53.(5) p. 2913-2924
- **Zhang, Qin**. Image Processing for Ice Parameter Identification in Ice Management. PhD thesis, Norwegian Univ. Science & Technology, Trondheim, Norway, 2015
- **Heyn, Hans-Martin; Skjetne, R**. A system for measuring ice-induced accelerations and identifying ice actions on the CCGS Amundsen and a Swedish Atle-class icebreaker. Accepted for the 35th Int. Conf. on Ocean, Offshore & Arctic Eng. (OMAE 2016), Busan, South Korea, June 19-24, 2016

Research campaign: Marine archaeology survey in the Arctic

Supervisors: Professors Asgeir J. Sørensen, Martin Ludvigsen, Geir Johnsen and Roger Skjetne
PhD candidates: Øyvind Ødegård, Petter Norgren

Archaeologists estimate that there could be more than 1000 historical wrecks in the waters surrounding Svalbard. The Arctic environment makes it difficult to carry out diver based marine archaeological surveys in these areas, and until now, there have been no archaeological investigations of wreck sites.

In September 2015, NTNU AMOS PhD candidates Øyvind Ødegård and Petter Norgren, together with professors and students from UNIS, investigated a wreck in Trygghamna that was discovered by the Norwegian Hydrographic Service in 2007. The wreck was assumed to be Figaro, a German barque built in 1879 that served as a floating whalery in Svalbard starting in 1904, until it caught fire and sank in 1908.

From two Polarcirkel boats, a REMUS 100 AUV and a Seabotix mini-ROV could be used in parallel operations. The AUV's high resolution side scan sonar provided a detailed overview of the wreck site before the mini-ROV was deployed to inspect the wreck with an HD-camera. While one group explored and recorded the wreck with the mini-ROV, the other group continued to explore other parts of Trygghamna with the AUV.

The investigation confirmed that the wreck was Figaro and showed that the remains of the old ship were very well preserved after over 100 years on the seabed. The 50 metre-long wreck also held a surprise for the researchers; it was teeming with life. Barnacles, algae and other organisms covered most of the wreck, making it not only a cultural heritage site but also a rich marine ecosystem.

The team only spent a few hours at the wreck site, but they gathered a great deal of data that will yield valuable information on the history of Figaro in particular but also on the conditions for underwater cultural heritage in the Arctic in general. The wreck of Figaro is currently the world's northernmost registered underwater cultural heritage site.

Figure 69 *(NTNU/AUR-lab): The team; Sonar image of FIGARO; HD-video screenshot showing details of the barrel lid found inside the wreck.*

Media coverage:

- NRK.no, Forskarane har aldri funne skipsvrak så langt nord før no: – Dette er berre starten, 19 September 2015: http://www.nrk.no/troms/har-funne-det-nordlegaste-skipsvrak-i-verda_-_-dette-er-berre-starten-1.12560855

Related publication:

- **Nilssen, Ingunn; Ødegård, Øyvind; Sørensen, Asgeir Johan; Johnsen, Geir; Moline, Mark A.; Berge, Jørgen.** Integrated environmental mapping and monitoring, a methodological approach to optimize knowledge gathering and sampling strategy. Marine Pollution Bulletin 2015;Volume 96.(1-2) p. 374-383

HONOURS AND AWARDS

BEST PAPER AWARDS IN 2015

Best Paper Award

Bryne, Torleiv Håland; Fossen, Thor I.; Johansen, Tor Arne. A Virtual Vertical Reference Concept for GNSS/INS Applications at the Sea Surface. 10th IFAC Conference on Manoeuvring and Control of Marine Craft; 2015-06-24 - 2015-06-26

Best Student Paper Award

Auestad, Øyvind Fidje; Perez, Tristan; Gravdahl, Jan Tommy; Sørensen, Asgeir Johan; Espeland, Trygve H. Boarding Control System - for Improved Accessibility to Offshore Wind Turbines. 10th IFAC Conference on Manoeuvring and Control of Marine Craft; 2015-06-24 - 2015-06-26

Best Poster Paper Award

Seron, María M.; Johansen, Tor Arne; De Doná, José A.; Cristofaro, Andrea. Detection and Estimation of Icing in Unmanned Aerial Vehicles using a Bank of Unknown Input Observers. Australian Control Conference; 2015-11-03 - 2015-11-05

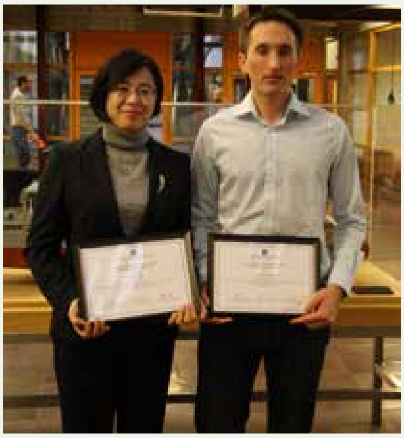
NEW HONORARY POSITIONS IN UNIVERSITIES AND SOCIETIES

Professor Asgeir J. Sørensen has been awarded membership in the Norwegian Academy of Technological Sciences (NTVA) in 2015.

Professor Thor I. Fossen has been elected fellow of the Institute of Electrical and Electronics Engineers (IEEE) in 2015.

Affiliated professor Oleksandr Tymokha has become Corresponding Member in the National Academy of Sciences of Ukraine in 2015.

Professor Kristin Y. Pettersen was a Distinguished Lecturer at the University of Toronto, ECE Distinguished Lectures Series, in 2015.



For the first time, **the Moan-Faltinsen Best Paper Awards** were presented during MARINTEK's and NTNU's annual Christmas lunch on December 18, 2015, at the Marine Technology Centre.

The recipients were Zhijun Wei within marine hydrodynamics for her paper "Sloshing-induced Slamming in Screen-equipped Rectangular Tanks in Shallow-water Conditions", and Vegard Longva within marine structures for his paper "A Lagrangian–Eulerian Formulation for Reeling Analysis of History-dependent Multilayered Beams".

Figure 70 *(Xiaopeng Wu, NTNU): Zhijun Wei (left) and Vegard Longva (right) with their certificates.*

For more information about the achievements listed here as well as to retrieve more NTNU AMOS news, visit: www.ntnu.edu/amos/newsandevents

INNOVATION AND TRAINING OF PHD CANDIDATES

Project manager: Professor Ingrid Schjølberg, Director of NTNU Oceans
Partner: NTNU Technology Transfer AS

The NTNU AMOS Innovation Model

The motto of NTNU AMOS is a lively scientific heart giving sustainable value to society. The Centre has a strong focus on scientific excellence but also focuses on developing a culture for innovation and value creation.

Background

The Norwegian economy is now at a turning point. We are about to leave 15 golden years behind. The Norwegian economy has made use of favourable tailwinds and seized the opportunities offered. The other side of the coin is an economy that has become increasingly dependent on oil and is thereby more vulnerable to changes in oil prices and petroleum revenues. As we know, oil prices have fallen drastically in recent years, which puts our ability to restructure labour markets, industry and the public sector to the test. There is no crisis, but the expected decline in demand from the oil industry means that we must move towards a new normal situation. Norway needs to improve the industries where we already have a competitive advantage and stimulate the growth of new industries to finance welfare.

The fundamental challenge for Norway is to figure out how to secure Norwegian welfare in the future. We must defend our costs through internationally competitive and profitable companies. That means Norwegian companies must have a high knowledge content of products or services. Universities and research institutes are therefore one of the main sources of competitiveness for existing and new businesses.

The Centre of Excellence (CoE) NTNU AMOS has established a set of values to support the development of a culture for innovation: excellence, generosity, and courage. These values form the basis for the Centre's workplace culture: endorsing excellence in performance, promoting individuals' wellbeing, developing individuals' personal qualities and skills, encouraging openness in discussions, and generating research results for pioneering and original game-changing technology. This approach has the potential to create a paradigm shift in business opportunities. At NTNU AMOS, we create a culture for innovation by including innovation in the agenda.

NTNU AMOS will contribute to improve the international competitiveness of Norwegian industries, such as fisheries and aquaculture, shipping and oil and gas, deep sea mining, renewable energy and ocean monitoring and mapping.

To meet this challenge, the Centre has developed a new model for research and spin-offs that shall create clear and measurable value to Norwegian society. In 2014, the Centre started a PhD Innovation Program named *NTNU AMOS School of Innovation*. This programme addresses the nation's vital need for engineers with both technical and entrepreneurial expertise and is Norway's first engineering PhD Innovation Program. PhD candidates at NTNU AMOS will complete all the regular PhD requirements along with additional studies that prepare them for the opportunity to build an enterprise based on technical innovation.

Objectives:

- contribute to new industry and growth in the "blue" economy in Norway
- more PhD candidates becoming entrepreneurs
- more innovation in existing industry
- take an international position in research-based innovation

NTNU AMOS School of Innovation – building blocks

Knowledge of entrepreneurship is an important part of the Centre's innovation strategy. In 2015, many PhD candidates at the Centre have participated in the NTNU AMOS School of Innovation.

NTNU Technology Transfer AS have had a vital role in developing and organizing the innovation school together with the Centre's management team.

PhD candidates become innovators

NTNU AMOS Innovation Lunch

As part of building a culture for innovation, we have gathered the PhD candidates monthly at an NTNU AMOS innovation lunch, where the goal is to inspire the PhD candidates to extend their network and to build acceptance for innovation. In 2015, Solution Seeker AS, Haukr

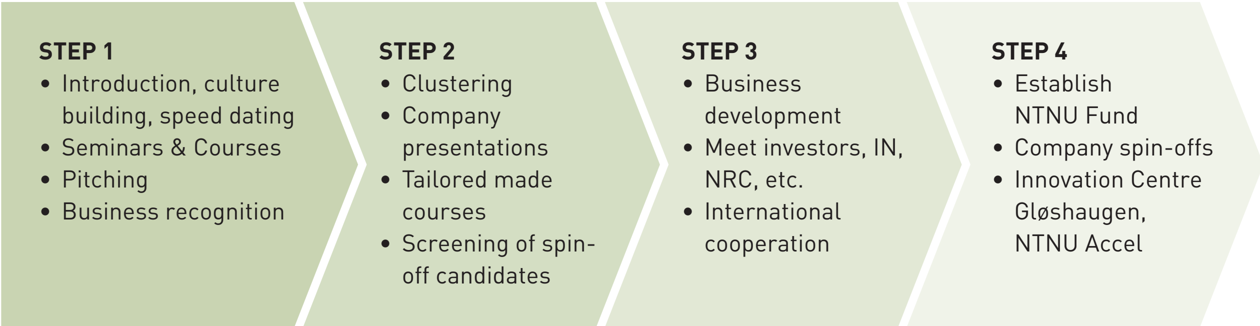


Figure 71: *The ladder describing the activities for building a culture for innovation and entrepreneurship at NTNU AMOS.*

AS, Havtek AS, NTNU Technology Transfer AS, and several other companies held short presentations during the PhD candidates' lunch break.

NTNU AMOS Executive Course

The Centre invited its PhD candidates to a 2-day course in intellectual property and business development that was custom-made for them.

The goal of the course was to increase their competence in the commercialization of technology, as well as their knowledge on how to optimize the commercial value of intellectual property and to give an introduction to test-driven entrepreneurship.

The course focused on how to create value from research through practical examples and offered an introduction to relevant methods and tools to structure and plan how to use results from research in a commercial setting, either in collaboration with existing industry or through establishing new ventures.

Representatives from the Intellectual Property Institute of Norway (IPIN) at NTNU, the Chalmers University of Technology and the Gothenburg School of Business, Economics and Law held the course.

The course's location was the new co-working space DIGS in Olav Trygvassons gate in the city centre of Trondheim, where several technology based start-ups from NTNU are located.

NTNU AMOS pitching event and team building

In September 2015, the Centre invited its PhD candidates to attend an NTNU AMOS pitching event and team building.

The PhD candidates compressed their research topics, interests and results into a short speech and presented them in front of a panel of real-life investors. The winner won a check for over 50,000 NOK for their research.

Figure 72 *(Emil Økstad, NTNU Technology Transfer): NTNU AMOS PhD candidates at executive course at DIGS in April 2015.*

In advance, all participants received the following training:

- Pitching: experience the spontaneity and rush of pitching to a live audience, develop your confidence and hone your message
- Performance training: how to present ideas succinctly and make them easy to understand for all audiences. Explore the use of metaphor, storytelling and other creative mediums to create informative and engaging pitches

We combined the pitching event with team building so all participants got the chance to build a network internally in NTNU AMOS and enjoy a free dinner.

The Centre will continue with the School of Innovation and other course and training activities in 2016 and has also started a collaboration with several centres for research-based innovation (SFIs) to consolidate the effort to bring more research-based innovation from the universities to the market.

Wavespring technology licensed to CorPower Ocean AB
In 2015, NTNU made a license agreement based on research from the former Centre of Excellence, CeSOS, and NTNU AMOS. The Swedish technology start-up CorPower Ocean AB was founded in 2009 to develop Wave Energy Converters (WEC). A highly efficient phase control technology, Wavespring, invented by PhD Jørgen Hals Todalshaug at NTNU, was a perfect match to Cor-Powers wave energy converter technology. The Wave-Spring technology has demonstrated a game-changing performance that is set to revolutionize wave power. It is a result of research on phase-controlled point absorbers that has been conducted in Trondheim since the 1970s.

Commercialization project VeriArc
VeriArc stands for "Verifying Arctic offshore field activities" and is a commercialization project at NTNU that has received significant funding from the NTNU Discovery fund. The objective is to commercialize a product around a dynamic simulator on ice-structure interaction (loads and responses), and find out how to utilize this in a commercial setting. The development of the numerical simulator is based on research and competence built up from numerous research projects on Arctic topics at NTNU. The SFI SAMCoT is the latest and largest effort in this direction, also including close collaboration with NTNU AMOS. The vision of VeriArc is to become

Figure 73 *(Steinar Kvam): Presentation at the pitching event and team building at Scandic Lerkendal, September 2015.*

"pioneers in verification of Arctic offshore activities", and the business idea is "safer and publically accepted Arctic offshore activities through verification of structure designs, operational procedures, and decision support tools using superior sea-ice simulation technology". The principal researchers initiating the VeriArc commercialization project are Professor Sveinung Løset, Assistant Professor Raed Lubbad, and Professor Roger Skjetne. More details are presented in:

- **Lubbad, Raed; Løset, Sveinung; Skjetne, Roger**. Numerical Simulations Verifying Arctic Offshore Field Activities. Proceedings - International Conference on Port and Ocean Engineering under Arctic Conditions 2015 ;Volume 2015-January.

NTNU AMOS attends the DNV GL Top Tech Program at UC Berkeley – Haas School of Business

The Haas School of Business, UCB, managed by professor Andrew M. Isaacs, has for several years organized a Top Tech Program with several meetings at UCB for select DNV GL employees. The programme has a strong innovation profile addressing various topics, such as business models, branding, sustainability, mega trends, enabling technologies, energy in transition, challenges and opportunities in the ocean space, etc. The talks are given by several invited lecturers from the US and the rest of the world. NTNU AMOS has been present with Professor Asgeir J. Sørensen the last three years. The topic for this year talk was *Marine Cybernetics - A view on underwater robotics, ocean space and arctic research.*

The Top Tech Program by UCB has also been an inspiration for NTNU AMOS in learning from innovation processes, experience and the mind set of UCB and Silicon Valley. Bjørgulf Haukelid has been a Top Tech coordinator at DNV GL. Haukelid was also engaged as a project manager in the research strategy process at the Faculty of Engineering Science and Technology, NTNU in 2011-2012, leading to NTNU's efforts to establish excellent research centres, including NTNU AMOS.

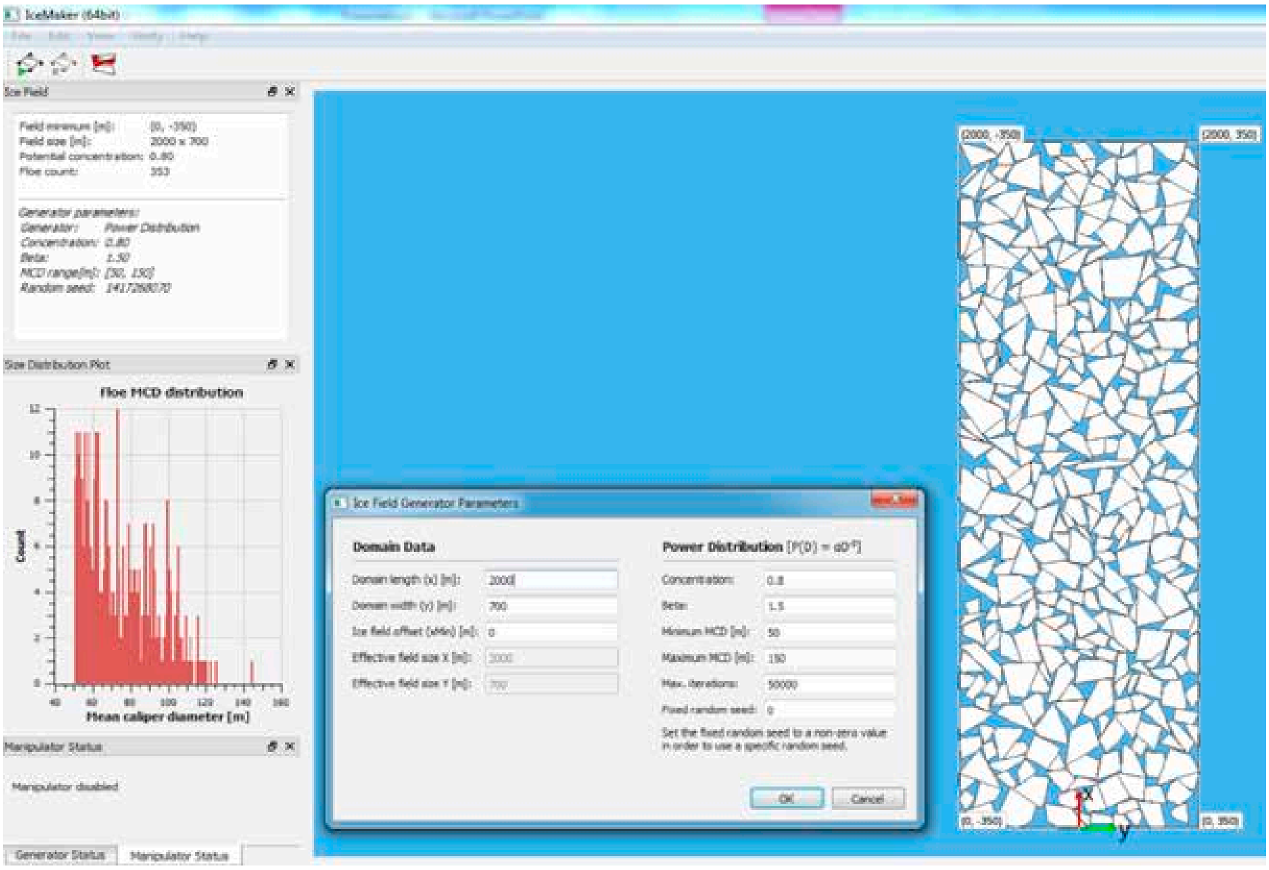


Figure 74 *(NTNU; Yulmetov): Snapshot of the IceMaker program developed at NTNU.*

Figure 75: *From left: Bjørgulf Haukelid (DNV GL), Marose Eddy (UCB), Asgeir J. Sørensen (NTNU) and Andrew M. Isaacs (UCB).*

NTNU AMOS spin-off companies founded in 2015

Eelume AS
Eelume AS develops a swimming detachable robotic arm for ROVs for better inspection and intervention in subsea installations.

The company is a new start-up from NTNU AMOS, with a goal of developing the first truly autonomous intervention vehicle (AIV) for subsea applications, both for the oil & gas and other industries. The technology is based on several years of research in developing snake robotics for land and sea applications.

The value proposition is to provide improved inspection and intervention capabilities compared to traditional ROV operations through superior accessibility and access to confined areas. This will be achieved by reducing the number of surface vessel days on each subsea installation and will thus significantly reduce the total cost of ownership for the end client.

BluEye Robotics AS
The company is developing a remote controlled subsea drone aimed at the semi-professional and consumer market. BluEye Robotics AS aims to develop underwater drones that will revolutionize the experience of exploring the ocean and that takes the user down to the seabed. In 2015, BluEye finalized their first two prototypes, which were used in expeditions across both the Atlantic and Pacific Oceans. The planned product launch is in the autumn of 2016.

Figure 76 *(BluEye): CEO Erik Dyrkoren, Borja Serra and Christine Spiten testing the PX underwater robot in the towing tank at MARINTEK.*

INTERVIEWS WITH PHD CANDIDATES

Andreas Reason Dahl

PhD candidate at NTNU AMOS

Age: 30
PhD topic: Nonlinear and Fault-Tolerant Control of Electric Power Production in Dynamic Positioning Vessels
Time left in the programme: 2 years
Supervisor: Professor Roger Skjetne
Co-supervisors: Professors Asgeir J. Sørensen and Tor Arne Johansen
Where are you from: Tromsø, Norway

Why did you choose to become a PhD candidate?
I really enjoyed working on my Master thesis: specialising in something and gaining deeper insight into that specific topic. Towards the end of my studies, I was encouraged to apply for a PhD position. Prof. Sørensen's enthusiasm about the hybrid power laboratory convinced me to take this opportunity.

How is it to be a PhD candidate at NTNU AMOS?
You feel privileged: there are lots of seminars and activities, interesting guest lectures and good facilities. As part of my teaching duties in the Marine Cybernetics laboratory, both the students and I get to work with advanced industrial-grade equipment.

On the social side, the colleagues are nice and there is even a budget at the Centre for team building activities. Especially for foreign employees and those who are not from Trondheim, these activities make it easier to fit in.

What is the best thing about being a PhD candidate?
Gaining deeper insight and understanding through several years of working with one research topic.

What is the worst thing about being a PhD candidate?
Publication pressure. The requirements for the PhD degree include a minimum number of papers. It demands integrity to not simply publish for the sake of fulfilling metrics.

Is it worth it?
Yes. Even though it is hard work, it can be very rewarding. For example, when you are on your way home from the office and all of a sudden, you find a new approach to one of your problems. Then, you can hardly wait to get back to work the next day.

What is your primary research field at NTNU AMOS?
New ways of controlling marine vessel power plants. Future marine vessels need smarter, greener and safer power management. Fault tolerance is a requirement to guarantee for safety while minimizing emissions.

Have you had any research stays abroad during your time at NTNU AMOS?
Yes. During the second semester, I stayed at the Technical University of Denmark for four months to learn about fault tolerant control. This fall, I had a month long academic stay in St. Petersburg at ITMO University to establish academic connections and possible cooperation, as well as refresh my Russian skills.

What are your plans for the future?
I would like to work in the industry at least some years, preferably in a Norwegian company with interests in Russia.

Anna Kohl

PhD candidate at NTNU AMOS

Age: 25
PhD topic: Hyperredundant Underwater Manipulators and Next Generation Intervention-AUVs
Time left in the programme: 1 year 9 months
Supervisor: Professor Kristin Y. Pettersen
Co-supervisors: Professors Jan Tommy Gravdahl, Asgeir J. Sørensen and Marilena Greco
Where are you from: Kulmbach, Germany

Why did you choose to become a PhD candidate?
While working on projects like my Master's thesis, I was always disappointed when I had to submit the work because that was around the time I felt that I was finally making progress. With the PhD studies, I hoped to get deeper into a topic and spend more time on it.

How is it to be a PhD candidate at NTNU AMOS?
It's awesome. I enjoy the working environment: This includes the excellent support by my supervisors as well as the general atmosphere. Everyone is very helpful, friendly and outgoing. Being a PhD candidate at NTNU AMOS means that you will have many colleagues who challenge you and help you out, but also many new friends.

What is the best thing about being a PhD candidate?
I get to work freely. I am flexible in my work, and I like setting myself new goals that I will reach within a few months – like lab experiments, theoretical work or presenting a paper at a conference. This way, finishing the PhD thesis seems less far away every time one of the intermediate goals is reached.

What is the worst thing about being a PhD candidate?
Being far away from home and not seeing my family and friends very often.

Is it worth it?
Yes, definitely.

What is your primary research field at NTNU AMOS?
Underwater snake robots. So far, I have looked into the modelling of such robots and control and guidance algorithms. In the future, I plan to do some experimental work in the MC-lab, and I will also look into using snake robots as manipulators.

Have you had any research stays abroad during your time at NTNU AMOS?
Not yet. We have invited a group from the University of Toronto in January 2016 to visit us and to start cooperating.

What are your plans for the future?
Finishing my PhD thesis in time. While doing so I hope to stumble over a good idea what to do afterwards. I would like to find a challenging and fulfilling job either in Norway or in Germany.

APPENDICES

NTNU AMOS personnel and collaborators

Management and administration

Name	Title	Acronym
Prof. Sørensen, Asgeir J.	Director	AJS
Prof. Fossen, Thor I.	Co-director	TIF
Wold, Sigrid Bakken	Senior executive officer	SBW
Bremvåg, Annika	Higher executive officer	AB

Key scientists

Name	Institution, department	Main field of research	Acronym
Prof. Amdahl, Jørgen	NTNU, Dept. Marine Technology	Structural load effects, resistance, accidental actions	JAM
Prof. Fossen, Thor I.	NTNU, Dept. Engineering Cybernetics	Guidance, navigation and control	TIF
Prof. Greco, Marilena	NTNU, Dept. Marine Technology	Marine hydrodynamics	MG
Prof. Johansen, Tor Arne	NTNU, Dept. Engineering Cybernetics	Optimization and estimation in control	TAJ
Prof. Pettersen, Kristin Y.	NTNU, Dept. Engineering Cybernetics	Automatic control	KYP
Prof. Sørensen, Asgeir J.	NTNU, Dept. Marine Technology	Marine control systems	AJS

Senior scientific advisers

Name	Institution, department	Main field of research	Acronym
Prof. Faltinsen, Odd M.	NTNU, Dept. Marine Technology	Marine hydrodynamics	OF
Prof. Moan, Torgeir	NTNU, Dept. Marine Technology	Marine structures	TM

Adjunct professors and adjunct associate professors

Name	Institution	Main field of research	Acronym
Adj. ass. prof. Bachynski, Erin E.	NTNU, Dept. Marine Technology	Wind energy/offshore renewable energy systems	EB
Prof. Blanke, Mogens	Technical Univ. of Denmark (DTU), Denmark	Automation and control	MB
Adj. prof. Fredheim, Arne	NTNU, Dept. Marine Technology	Fisheries and aquaculture	AF
Adj. ass. prof. Føre, Martin	NTNU, Dept. Engineering Cybernetics	Fisheries and aquaculture cybernetics	MF
Adj. ass. prof. Gao, Zhen (until summer 2015)	NTNU, Dept. Marine Technology	Wind energy/offshore renewable energy systems	ZG
Adj. ass. prof. Hassani, Vahid (from summer 2015)	NTNU, Dept. Marine Technology	Marine control	VH
Prof. Jensen, Jørgen Juncher	Technical Univ. of Denmark (DTU), Denmark	Wave-induced hydro-elastic response of ships	JJJ
Adj. prof. Lugni, Claudio	CNR-INSEAN, Italy	Marine hydrodynamics	CL
Adj. ass. prof. Nielsen, Ulrik Dam	Technical Univ. of Denmark (DTU), Denmark	Wave-ship interactions	UDN
Adj. ass. prof. Sokolova, Nadezda	SINTEF ICT	GNSS and integrated navigation systems	NS
Adj. ass. prof. Storvold, Rune	NORUT, Tromsø	Developing aircraft, sensors, and communication and control systems for air-borne remote sensing using unmanned aircraft	RST

Postdocs

Name	Institution	Main field of research	Acronym
Dr Amelin, Konstantin	NTNU, Dept. Engineering Cybernetics	Multi-agent AUV-systemer	KA
Dr Cristofaro, Andrea	NTNU, Dept. Engineering Cybernetics	Optimization	AC
Dr Hassani, Vahid (until summer 2015)	NTNU, Dept. Marine Technology	Marine control	VH
Dr Kim, Ekaterina	NTNU, Dept. Marine Technology	Understanding rare, extreme ice-structure collisions	EK
Dr Lekkas, Anastasios	NTNU, Dept. Marine Technology	Guidance and path planning for marine vehicles	AL

Affiliated scientists

Name	Institution	Main field of research	Acronym
Ass. prof. Alfredsen, Jo Arve	NTNU, Dept. Engineering Cybernetics	Automation in fisheries and aquaculture	JAA
Dr Breivik, Morten	NTNU, Dept. Engineering Cybernetics	Nonlinear and adaptive motion control	MBR
Ass. prof. Brekke, Edmund	NTNU, Dept. Engineering Cybernetics	Bayesian estimation with applications in parameter estimation, target tracking and autonomous navigation	EB
Prof. Gao, Zhen (from summer 2015)	NTNU, Dept. Marine Technology	Wind energy/offshore renewable energy systems	ZG
Prof. Imsland, Lars S.	NTNU, Dept. Engineering Cybernetics	Automatic control, optimization	LSI
Prof. Johnsen, Geir	NTNU, Dept. Biology	Marine biology	GJ
Dr Liljebäck, Pål	NTNU, Dept. Engineering Cybernetics	Snake robots	PL
Prof. Ludvigsen, Martin	NTNU, Dept. Marine Technology	Underwater technology and operations	ML
Dr Michailidis, Konstantinos	NTNU, Centre for Ships and Ocean Structures	Modelling and analysis of dynamic response in floating facilities for producing power from wind and waves	KM
Prof. Schjølberg, Ingrid	NTNU, Dept. Marine Technology	Underwater robotics	IS
Prof. Skjetne, Roger	NTNU, Dept. Marine Technology	Marine control systems	RS
Prof. Tymokha, Oleksandr	NTNU, Dept. Marine Technology	Mathematical aspects of hydromechanics with emphasis on free-surface problems (sloshing)	OT
Prof. Utne, Ingrid B.	NTNU, Dept. Marine Technology	Safety critical systems and systems engineering	IBU

Technical staff, directly funded by NTNU AMOS

Name	Institution, department	Acronym
Volden, Frode	NTNU, Dept. Marine Technology	FV
Semb, Lars	NTNU, Dept. Engineering Cybernetics	LS

Visiting researchers

Name	Institution, department	Main field of research	Acronym
Prof. Arcak, Murat	Univ. of California, Berkeley, USA	Cooperative control design	AM
Dr Colicchio, Giuseppina	CNR-INSEAN, Italy	Mesh generation and analysis for computational fluid mechanics	GC
Prof. Prpic-Orsic, Jasna	Univ. of Rijeka, Croatia	CO_2 emission from ships in waves	JP
Dr Sasa, Kenji	Kobe University, Japan	Seakeeping of ships and ocean structures	KS
Prof. Teel, Andrew R.	Univ. of California, Santa Barbara, USA	Hybrid dynamical systems	?

PhD candidates with financial support from NTNU AMOS

Name	Period (yyyymmdd)	Supervisor	Topic
Belleter, Dennis	20130819-20160818	KYP	Multi-agent control systems
Bore, Pål Takle	20150901-20180901	JAM	Intelligent aquaculture structures
Brodtkorb, Astrid H.	20140101-20170630	AJS	Dynamic positioning in extreme seas
Cisek, Krzysztof	20140501-20170430	TAJ	Multi-body unmanned aerial systems
Eidsvik, Ole A.	20150801-20180701	IS	Design and development of unmanned underwater vehicles
Fortuna, João	20140815-20170814	TIF	Autonomous UAV recovery and rendezvous on moving ships
Gryte, Kristoffer	20150811-20180810	TIF	Fixed-wing UAV operations from autonomous floating docking station
Hanssen, Finn-Christian W.	20130826-20160816	MG	Nonlinear wave loads on marine structures in extreme sea states
Horn, Jan-Tore Haugan	20150101-20180430	JAM	Stochastic dynamic simulations of offshore wind turbines with integrated control and monitoring
Jørgensen, Erlend Kvinge	20140818-20170817	IS	Autonomous subsea IMR operations using sensor fusion and structure knowledge
Klausen, Kristian	20130805-20160804	TIF	Deployment, search and recovery of marine sensors using multiple rotary wings UAVs
Kohl, Anna	20140801-20170731	KYP	Hyperredundant underwater manipulators and next generation intervention-AUVs
Leira, Fredrik Stendahl	20130625-20160624	TIF	Infrared object detection & tracking in UAVs
Ma, Shaojun	20140805-20170804	MG	Manoeuvring of a ship in waves
Merz, Mariann	20130812-20160811	TAJ	Deployment, search and recovery of marine sensors using a fixed-wing UAV
Muntadas, Albert Sans	20140501-20170430	KYP	Integrated underwater navigation and mapping based on imaging and hydro-acoustic sensors
Nam, Woongshik	20140811-20170810	JAM	Structural resistance of ships and offshore structures subjected to cryogenic spills
Nielsen, Mikkel Cornelius	20140815-20170814	MB	Fault-tolerance and reconfiguration for collaborating heterogeneous underwater robots
Nornes, Stein M.	20130826-20160825	AJS	Simultaneous mapping, navigation and monitoring with unmanned underwater vehicle using sensor fusion
Paliotta, Claudio	20140106-20170105	KYP	Marine multi-agent systems: coordinated and cooperative control for intelligent task execution and collision avoidance
Sauder, Thomas	20150803-20180802	AJS	Real-time hybrid testing of floating systems
Shen, Yugao	20130812-20160811	MG	Limiting operational conditions for a well boat
Siddiqui, Mohd Atif	20140813-20170812	MG	Manoevring of a damaged ship in waves
Smilden, Emil	20150101-20180430	AJS	Reduction of loads, fatigue and structural damage on an offshore wind turbine
Sørensen, Kim Lynge	20130601-20160531	TAJ	Autonomous ice protection of UAVs
Tutturen, Svenn Are	20140101-20161231	RS	Topics in motion control of offshore vessels
Vilsen, Stefan A.	20140201-20180131	AJS/HG	Hybrid model testing of marine systems
Wiig, Martin Syre	20140815-20180814	KYP	Motion planning for autonomous underwater vehicles
Yu, Zhaolong	20140811-20170810	JAM	Ship/ship and ship/offshore installation collisions including fluid structure interaction
Zolich, Artur	20140401-20170331	TAJ	Autonomous control and communication architectures for coordinated operation of unmanned vehicles (UAV, AUV, USV) in a maritime mobile sensor network
Ødegård, Øyvind	20130820-20170819	AJS	Autonomous operations in marine archaeology - technologies and methods for managing underwater cultural heritage in the Arctic

PhD candidates associated with NTNU AMOS with other financial support

Name	Period (yyyymmdd)	Super-visor	Topic
Aamodt, Inga	20120316-20160316	GJ/AJS	Use of underwater robotics and optical sensors in distribution-mapping and monitoring of physiology of brown, red and green macroalgae
Acero, Wilson G.	20130801-20160731	TM	Development of methods and procedures for offshore wind turbine installation activities
Albert, Anders	20130826-20170825	LI	Mission and path optimisation for mobile sensor network operations
Albrektsen, Sigurd M.	20140101-20161231	TAJ	Integrated observer design with a north-seeking strapdown MEMS-based gyrocompass and machine vision
Andersson, Leif Erik	20140316-20170315	LI	Iceberg and sea ice drift estimation and prediction
Borri, Daniele	20100811-20151031	MG	Hydrodynamics of oil spills from oil tankers
Borup, Kasper T.	20130516-20160515	TIF	Model-based nonlinear integration filters for INS and position measurements
Bryne, Torleiv H.	20130815-20160804	TIF	Optimal sensor fusion for marine vessels using redundant IMUs and position reference systems
Bø, Torstein I.	20130501-20160731	TAJ	Power management based on model predictive control
Candeloro, Mauro	20110901-20150831	AJS	Control systems for underwater vehicles with increased level of autonomy by using sensor fusion and vision systems
Cheng, Zhengshun	20140601-20160531	TM/ZG	Dynamic modeling and analysis of floating vertical axis wind turbines
Cho, Seong-Pil	20140804-20170803	TM/ZG	Dynamic modelling and analysis of floating wind turbines with emphasis on the behavior in fault conditions
Dahl, Andreas Reason	20130819-20160818	RS	Nonlinear and fault-tolerant control of electric power production in Arctic DP vessels
Dahlin, Christopher	201508xx- 201807xx	TAJ	Intelligent data acquisition in maritime UAS
Eriksen, Bjørn-Olav H.	20150803-20180802	MBR	Collision avoidance for autonomous surface vehicles
Fernandes, Daniel De Almeida	20100816-20141015	AJS	GNC systems for underwater vehicles
Flåten, Andreas L.	20150803-20180802	EB	Multisensor tracking for collision avoidance
Fusini, Lorenzo	20121001-20151231	TIF	Robust UAV attitude and navigation system for marine operations using nonlinear observers and camera measurements
Ghane, Mahdi	20150101-20171231	TM/ZG	Dynamic modelling and analysis of floating wind turbines with emphasis on the behavior in fault conditions
Hansen, Jakob Mahler	20130801-20160731	TIF	Nonlinear observers for tight integration of IMU and GNSS pseudo-range and carrier-phase-ambiguity resolution
Hassel, Martin	20140101-20161231	IU	Risk and safety of marine operations
Hegde, Jeevith	20140822-20170821	IS	Safety and reliability of marine underwater autonomous vehicles
Helgesen, Håkon Hagen	20150817-20181116	TAJ	UAV scouting system for autonomous ships
Henriksen, Eirik H.	20140804-20170803	IS	Next generation subsea factories for autonomous IMR operations
Heyn, Hans-Martin	20140813-20180812	RS	Fault-tolerant control and parameter estimation for thruster assisted position mooring in Arctic offshore conditions
Jørgensen, Ulrik	20100830-20140331	RS	Autonomous underwater ice observation system
Kelasidi, Eleni	20120318-20150317	KYP	Underwater snake robots
Lin, Li	20110810-20160531	TM/ZG	Numerical simulations of offshore wind turbine installation
Mathisen, Siri Holthe	20140818-20170817	TAJ	Embedded optimization for autonomous unmanned aerial vehicle mission planning and guidance
Moe, Signe	20130801-20160731	KYP	Guidance and control of marine vehicles
Nilssen, Ingunn	201204xx-201604xx	GJ/AJS	Integrated environmental monitoring; taking environmental data into decision making processes

Norgren, Petter	20130301-20170428	RS	AUVs for subsurface monitoring of sea-ice and icebergs
Olofsson, Harald L. J.	20151012-20181011	TIF	Bayesian iceberg risk management
Pedersen, Morten D.	20100110-	TIF	Modeling and control systems for wind turbines
Rejani Miyazaki, Michel	20130503-20170502	AJS	Control of hybrid power plants
Ren, Zhengru	20160101-20181231	RS	Monitoring and control of crane operations for fixed and floating offshore wind turbines
Rogne, Robert	20130801-20160731	TAJ	Fault-tolerant sensor fusion by exploiting redundant inertial measurements
Rokseth, Børge	20140815-20170814	IU	A new approach for handling risk in dynamic position systems for marine vessels
Sanfilippo, Filippo	20110901-20150831	KYP	Alternative and flexible control methods for robotic manipulators
Skjong, Espen	201408xx- 201708xx	TAJ	Optimization based design of modular power management systems for modern ships, with focus on efficiency and fuel consumption
Song, Ming	20140901-20160630	JAM	Numerical analysis of ship-ship and ship-ice collision
Storheim, Martin	20110901-20150831	JAM	Structural response to extreme impacts
Stovner, Bård Bakken	20140801-20170731	IS	Localization and perception for safe underwater ROV intervention
Strand, Ida M.	20130801-20160731	AJS	External sea loads and internal hydraulics of closed flexible cages
Sverdrup-Thygeson, Jørgen	20150301-20180531	KYP	Motion control and redundancy resolution for hybrid underwater manipulators
Sørensen, Mikkel Eske Nørgaard	20140825-20170824	MBR	Nonlinear and adaptive control of unmanned vehicles for maritime applications
Thieme, Christoph A.	20140901-20170731	IU	Human and organizational factors in unmanned underwater operations
Wenz, Andreas Wolfgang	20150601-20180531	TAJ	Fault tolerant control and automatic de-icing for unmanned aerial vehicles
Wilthil, Erik F.	20150803-20180803	EB	Target tracking under navigation uncertainty
Zhao, Yuna	20140901-20170831	TM/ZG	Safety assessment of marine operations related to installation of offshore wind turbine

Annual accounts and man-year efforts

Number of researchers and personnel man-years according to category and nationality

Nationality	Key professor	Adjunct/ Ass.prof.	Affiliated scientist	Scientific advisor	Postdoc	Visiting professor/ researcher	PhD	Ass. PhD	Admini-strative staff *)	SUM
Norwegian	5	3	11	2			15	24	5	65
Other nationalities	1	8	2		5	5	16	26	1	64
SUM	6	11	13	2	5	5	31	50	6	129
Man-years	3.5	2.2	5.8	2.0	2.7	0.6	27.5	39.8	3.2	87.3

*) Incl. technical staff

Total man-year efforts

Man-years	2015
Centre director	0.3
Co-director	0.2
Adm. personnel	1.7
Technical staff	1.0
Summary	3.2
Key professors	3.5
Adjunct prof./adj. ass. prof.	2.2
Affiliated prof./scientists	7.8
Postdocs	2.7
Visiting researchers	0.6
PhD candidates*)	67.3
Total research man-years	84.1
Total	87.3

*) incl. PhD candidates associated with NTNU AMOS with other financial support

Annual accounts

Amount in NOK 1000	Note	Accounted income and costs
Operating income		
The Research Council of Norway		19 435
NTNU	1	29 222
Others	2	6 259
In-kind	3	11 753
Sum operating income		66 669
Operating costs		
Salary and social costs	4	48 480
Equipment investments		1 291
Procurement of R&D services		3 066
Other operating costs	5	5 519
In-kind	3	11 753
Sum operating costs		70 109
Year end allocation		**-3 440**
Opening balance 2015		6 814
Closing balance 2015		3 374

Note 1: Accounted income: Fellowships and cash contribution to operation
Note 2: Accounted income: Contribution from industry sponsors: DNV GL, Statoil, SINTEF ITC, SINTEF FA, MARINTEK
Note 3: In-kind contribution: MARINTEK, SINTEF FA, NTNU
Note 4: Accounted costs: Personnel costs (salary and social costs) covered by NTNU AMOS
Note 5: Accounted costs: Other operating costs, including travelling, computer equipment

Research and education

PhD courses

Code	Subject	Professor in charge
MR8053	Stochastic Methods Applied in Nonlinear Analysis of Marine Structures	Torgeir Moan and Zhen Gao
MR8300	Hydrodynamic Aspects of Marine Structures 1	Marilena Greco
MR8404	System Safety	Ingrid B. Utne
MR8306	Hydrodynamic Aspects of Marine Structures 2	Trygve Kristiansen
MR8500	Advanced Topics in Marine Control Systems	Roger Skjetne
MR8501	Advanced Topics in Structural Modelling and Analysis	Jørgen Amdahl
TK8102	Nonlinear Observer Design	Edmund Brekke
TK8103	Advanced Nonlinear Systems	Kristin Y. Pettersen

Master courses

Code	Subject	Professor in charge
TMR4120	Underwater Engineering, Basic Course	Martin Ludvigsen
TMR4195	Design of Offshore Structures	Jørgen Amdahl
TMR4205	Buckling and Ultimate Strength Analysis of Marine Structures	Jørgen Amdahl
TMR4215	Sea Loads	Marilena Greco
TMR4217	Hydrodynamics of High-speed Marine Vehicles	Marilena Greco
TMR4240	Marine Control Systems	Asgeir J. Sørensen
TMR4243	Marine control systems II	Roger Skjetne
TMR4290	Marine Electric Power and Propulsion Systems	Roger Skjetne
TMR4515	Marine Control Systems, Specialization Course	Asgeir J. Sørensen
TMR4505	Integrated Dynamic Analysis of Wind Turbines	Torgeir Moan and Zhen Gao
TMR4585	Marine Subsea Engineering, Specialization Course	Martin Ludvigsen
TTK4	Unmanned Aircraft	Rune Storvold
TTK4115	Linear System Theory	Tor Arne Johansen
TTK4130	Modeling and Simulation	Lars S. Imsland
TTK4150	Nonlinear Control Systems	Kristin Y. Pettersen
TTK4190	Guidance and Control of Vehicles	Thor I. Fossen
TTK4225	Systems Theory, Introduction	Edmund Brekke
TTK5	Kalman Filtering and Navigation	Nadezda Sokolova

PhD degrees

Name	Topic	Supervisor
De Vaal, Jacobus	Aerodynamic Modelling of Floating Wind Turbines	Torgeir Moan
Fernandes, Daniel	An Output Feedback Motion Control System for ROVs: Guidance Navigation and Control	Asgeir J. Sørensen
Fredriksen, Arnt G.	A Numerical and Experimental Study of a Two-dimensional Body with Moonpool in Waves and Current	Odd M. Faltinsen
Kelasidi, Eleni	Modeling, Control and Energy Efficiency of Underwater Snake Robots	Kristin Y. Pettersen
Nejad, Amir Rasekhi	Dynamic Analysis and Design of Gearboxes in Offshore Wind Turbines in a Structural Reliability Perspective	Torgeir Moan
Sanfilippo, Filippo	Alternative and Flexible Control Methods for Robotic Manipulators	Kristin Y. Pettersen

Rezapour, Ehsan	Model-based Locomotion Control of Underactuated Snake Robots	Kristin Y. Pettersen
Wang, Kai	Modelling and Dynamic Analysis of a Semi-submersible Floating Vertical Axis Wind Turbine	Torgeir Moan
Zhao, Bo	Particle Filter for Fault Diagnosis: Applications to Dynamic Positioning Vessel and Underwater Robotic	Roger Skjetne

Master degrees

Name	Topic	Supervisor:
Andersen, Andreas	Simulering av Marine Løfteoperasjoner med Fokus på Kontroll av Konstruksjonsrepons	Jørgen Amdahl
Billington, Thor Helge	Online Shape Estimation of Icebergs at Sea	Roger Skjetne
Bore, Pål Takle	Ultimate- and Fatigue Limit State Analysis of a Rigid Offshore Aquaculture Structure	Jørgen Amdahl
Brask, Annette Kristin	Control and Estimation of Wave Energy Converters	Roger Skjetne
Cetin, Recep	Indoor Navigation System and Suspended Load Control for Multirotors	Thor I. Fossen
Drozdik, Ron	Dynamic Positioning for ROV Operating in Fish Farms	Jo Arve Alfredsen
Eidsvik, Ole Alexander	Identification of Hydrodynamic Parameters for Remotely Operated Vehicles	Ingrid Schjølberg
Erdal, Mads	Optimal Thrust Allocation for Dynamic Positioning Systems using Mixed Integer Linear Programming	Lars S. Imsland
Eriksen, Bjørn-Olav Holtung	Horizontal Collision Avoidance for Autonomous Underwater Vehicles	Kristin Y. Pettersen
Fehn, Manuel Andre	Spare Parts Evaluation in the Oil and Gas Industry	Ingrid B. Utne
Fernandez Cordova, Gonzalo Alfonso	Ice Loads and Induced Dynamic Responses of a Monopile Wind Turbine	Torgeir Moan
Flåten, Andreas L.	Experimental Monitoring of Sea Ice Using Unmanned Aerial Systems	Lars S. Imsland
Fossan, Pål Alexander	Ultimate- and Fatigue Limit State Analysis of a Rigid Offshore Aquaculture Structure	Jørgen Amdahl
Frølich, Marcus	Automatic Ship Landing System for Fixed-Wing UAV	Thor I. Fossen
Furseth, Jostein	Modeling and Control of VTOL Flying Wing with Thrust Vectoring	Thor I. Fossen
Grindheim, Vegard	Accurate Drop of a GPS Beacon Using the X8 Fixed-Wing UAV	Thor I. Fossen
Gryte, Kristoffer	High Angle of Attack Landing of an Unmanned Aerial Vehicle	Thor I. Fossen
Hansen, Jørgen Lima	Analysis and Design of Ship Collision Barriers on a Submerged Floating Tunnel subjected to Large Ship Collisions	Jørgen Amdahl
Helgesen, Håkon Hagen	Object Detection and Tracking Based on Optical Flow in Unmanned Aerial Vehicles	Thor I. Fossen
Holsen, Sigurd Andreas	DUNE: Unified Navigation Environment for the REMUS 100 AUV	Asgeir J. Sørensen
Horn, Jan-Tore Haugan	Stochastic Dynamic Analysis of Offshore Bottom-Fixed Structures	Jørgen Amdahl
Hosen, Jesper	A Vision-Aided Navigation System based on Optical Flow	Thor I. Fossen
Hvamb, Knut	Motion Planning Algorithms for Marine Vehicles	Morten Breivik
Idland, Tor Kvestad	Marine Cybernetics Vessel CS Saucer	Roger Skjetne
Jacobsen, Nanna Martine	Hull Monitoring and Assessment of Hatch Corners and Hatch Opening Distortion	Jørgen Amdahl
Kang, Gahyeong	Risk Assessment of Ship's Fuel Change-over Process	Ingrid B. Utne
Kjølleberg, Joakim	Weather Routing of Supply Vessels in the North Sea	Asgeir J. Sørensen
Larssen, Guro	Ice Detection and Tracking Based on Satellite and Radar Images	Roger Skjetne
Meneses Pereira da Silva, Joao Francisco da Cunha	Managed Pressure Cementing	Lars S. Imsland
Mo, Sigrid Marie	Development of a Simulation Platform for ROV systems	Ingrid Schjølberg
Møgster, Christian	Bayesian Estimation of Non-Stationary Ship Response Spectra	Asgeir J. Sørensen
Nous, Roel Johannes Maria	A Dynamic Approach to Evaluating the Effect of Slamming on a Jacket Foundation Template Lowered Through the Wave Zone	Torgeir Moan
Ohrem, Sveinung Johan	Development of a Dynamic Positioning System for Merlin WR 200 ROV	Kristin Y. Pettersen
Palm, Astrid Maria	Knekking og Omfordeling av Laster i Redundante Platekonstruksjoner	Jørgen Amdahl
Paust, Henrik Sogn	Finite Element Modeling and Structural State Estimation of a Bottom Fixed Offshore Wind Turbine	Asgeir J. Sørensen

Raaen, Stine Nicolaysen	Team Situation Awareness in Practice	Kristin Y. Pettersen
Rabanal, Ole Maurice Røste	Comparing Controllers for Dynamic Positioning of Ships in Extreme Seas	Morten Breivik
Ren, Zhengru	Fault Tolerant Control of Thruster-Assisted Position Mooring System	Roger Skjetne
Roald, Ann Louise	Path Planning for Vehicle Motion Control Using Numerical Optimization Methods	Morten Breivik
Røli, Jon-Håkon Bøe	Cooperative Control and RTK Navigation System for Multirotors	Thor I. Fossen
Saccoman, Marine Yvette Josette	Coupled Analysis of a Spar Floating Wind Turbine Considering both Ice and Aerodynamic Loads	Torgeir Moan
Sandved, Fredrik	Remote Control and Automatic Path-following for C/S Enterprise I and ROV Neptunus	Roger Skjetne
Schultz, Eirik	Modelling and Control of a Two-Body Offshore Wave Energy Converter	Asgeir J. Sørensen
Smilden, Emil	Preventing Tower Resonance Induced by Thrust Variations on a Large 10MW Wind Turbine	Asgeir J. Sørensen
Sodeland, Per Sondre	Combined Dynamic Positioning and Optimal Wave Frequency Motion Damping of Surface Effect Ship	Asgeir J. Sørensen
Spockeli, Bjørn Amstrup	Integration of RTK GPS and IMU for Accurate UAV Positioning	Thor I. Fossen
Stenersen, Henning Seeberg	Construction and Control of an Autonomous Sail Boat	Morten Breivik
Stenersen, Thomas	Guidance System for Autonomous Surface Vehicles	Kristin Y. Pettersen
Strand, Anders Salberg	Fire Resistance of Unmanned Wellhead Jackets	Jørgen Amdahl
Strømsøyen, Simen	Propulsion Methods for Under Water Snake Robots	Asgeir J. Sørensen
Sæther, Arne Kristian	An Experimental Investigation on Bio-fouling Induced Drag	Marilena Greco
Trnka, Kenan	Localization and Tracking of Ships and Objects Using a UAV Mounted Thermal Imaging Camera	Thor I. Fossen
Tvedt, Peter Kristian Hindar	Human and Organizational Factors in Vessel-Platform Collision Risk on the Norwegian Continental Shelf	Ingrid B. Utne
Valle, Eirik	Marine Telepresence System	Roger Skjetne
Vestum, Emil	Wind Powered Marine Vehicle	Asgeir J. Sørensen
Visser, Niels	Experimental Set-up of the Double Slip Joint	Torgeir Moan
Vittori, Felipe Eduardo	Design and Analysis of Semi-submersible Floating Wind Turbines with Focus on Structural Response Reduction	Torgeir Moan
Voortman, Ralph Lucas Bernard	State-of-the-art Design Methods for Wind Turbine Towers	Torgeir Moan
Wabakken, Iselin	Application of RCM to Construct a Maintenance Program for a Maritime Vessel	Ingrid B. Utne
Wilthil, Erik Falmår	Singularity-Free Navigation System for an Autonomous Unmanned Aerial Vehicle	Edmund F. Brekke
Xu, Kun	Design and Analysis of Mooring System for Semi-submersible Floating Wind Turbines in Shallow Water	Torgeir Moan
Zhu, Wenbo	Numerical Wave Tank for Nonlinear Waves in Various Water Depths	Marilena Greco
Øien, Pauline Kværnes	Physical Investigation of Slamming Loads on a 2D Body	Marilena Greco

Innovation

Innovation meetings

Date	Activity	Participants
29 January	Havtek AS - ups and downs as an entrepreneur in a technology based spin-off, by Sven Jørund Kolstø	PhD candidates and postdocs
9-10 April	NTNU AMOS Executive Course in the commercialization of research, by NTNU Technology Transfer AS	PhD candidates and postdocs
28 May	Presentation of Haukr AS, by Karen Juul Skarbø	PhD candidates and postdocs
11 September	Pitching course, by NTNU Technology Transfer AS	PhD candidates and postdocs
24 September	NTNU AMOS Investor Day, by NTNU Technology Transfer AS	PhD candidates and postdocs, key personnel

New NTNU AMOS spin-off companies

Name	Founders
BluEye Robotics	Erik Dyrkoren, Prof. Martin Ludvigsen, Prof. Roger Skjetne, Christine Spiten
Eelume AS	Prof. Kristin Y. Pettersen, Dr Pål Liljebäck, Prof. Asgeir J. Sørensen, Prof. Jan Tommy Gravdahl, Associate Prof. Øyvind Stavdahl

New patents

Title	Name	Patent/licence nr.
Underwater Manipulator Arm Robot	Kristin Y. Pettersen, Pål Liljebäck, Asgeir J. Sørensen, Øyvind Stavdahl, J. Tommy Gravdahl, Aksel Transeth	United Kingdom Patent Application No. 1501479.8
Guidance of Underwater Snake Robots	Kristin Y. Pettersen, Pål Liljebäck, Eleni Kelasidi and J. Tommy Gravdahl	United Kingdom Patent Application No. 1417625.9
Guidance of Underwater Snake Robots	Kristin Y. Pettersen, Pål Liljebäck, Eleni Kelasidi and J. Tommy Gravdahl	International (PCT) Patent Application, PCT/EP2015/072923

Workshops

Innovation meetings

Date	Workshop/seminar	Topic
9-10 February	Oppdal Workshop for NTNU AMOS researchers	Presentation and discussion of research results for all NTNU AMOS research groups
11-13 May	Meetings of NTNU AMOS' Scientific Advisory Board	Review of status and scientific advices for NTNU AMOS research
9-10 June	NTNU AMOS user panel on smarter, safer, greener marine operations	Support dissemination and user interaction on NTNU AMOS research area - smarter, safer, greener marine operations
4-11 October	Breaking the Surface	HR training for NTNU AMOS employees
29-30 October	NTNU AMOS Days	Strategic two-day seminar for NTNU AMOS employees and partners

Guest lectures and seminars by visitors to NTNU AMOS

Date	Speaker	Topic
2 February	Prof. R. Andrew Schwartz, Michigan Technological University, USA	Model Updating of Spinning Beam Structures for Load Characterization and Structural Health Monitoring Applications
18 February	Prof. Manfredi Maggiore, University of Toronto, Canada	Reduction Principles for Hierarchical Control Design
4 March	Prof. Jasna Prpić-Oršić, University of Rijeka, Croatia	A Greener Approach to Ship Design and Optimal Route Planning
9 March	Dr Yanlin Shao, Sevan Marine ASA, Norway	Harmonic Polynomial Cell (HPC) Methods and its Applications in Marine Hydrodynamics
16 March	Dr Giuseppina Colicchio, CNR-INSEAN, Italy	Mesh Generation and Analysis for Computational Fluid Mechanics
23 March	Dr Claudio Lugni, NTNU AMOS and CNR-INSEAN, Italy	Wave Impacts in Sloshing Flows
13 April	Dr Helge Aagaard Madsen, DTU Wind Energy (Risø), Denmark	Aerodynamic Induction Models for HAWT´s and VAWT´s in HAWC2 with Recent Updates
23-29 April	Dr Antonio Loría, French National Council of Scientific Research (CNRS) and Laboratoire de Signaux et Systèmes, France	Lecture Series on Stability and Stabilization of Time-varying Systems
8 May	Dr Kari Tammi, VTT Technical Research Centre, Finland	Energy Flow Simulation Analysis for Optimizing Vessel Energy Efficiency
8 May	Jackson Potter, VTT Technical Research Centre, Finland	Using and Improving the Steam System Model in a Ship Energy Flow Simulator
11 May	Prof. Randal W. Beard, BYU, Utah, USA	Research Activities in Small Unmanned Air Vehicles
18 May	Dr Ahmed Chemori, University of Montpellier, France	Control of Underwater Vehicles: From Design to Real-Time Experiments
26-28 May	Prof. Murat Arcak, U.C. Berkeley, USA	Compositional Control Synthesis and Verification for Networks
8 June	Prof. Spyros Voutsinas, National Technical University of Athens, Greece	Vortex Methods for Wind Turbines
3 September	Dr Inge Lotsberg, DNV GL, Norway	Capacity of Grouted Connections Subjected to Dynamic Loading
7-18 September	Prof. Andrew R. Teel, University of California at Santa Barbara, USA	Intensive Course on Stochastic Hybrid Dynamical Systems
11 September	Prof. Andrew R. Teel, University of California at Santa Barbara, USA	Hybrid Systems Approach to Global Synchronization and Coordination of Multi-agent Sampled-data Systems
30 September	Prof. Maarja Kruusmaa, Tallinn University of Technology, Estonia	Bioinspired Underwater Robots – Locomotion and Sensing
2 October	Prof. Henk Nijmeijer, Eindhoven University of Technology, the Netherlands	Cooperative Mechanical Systems: Past, Present and Future
9 October	Knut Eriksen, Oceaneering International, Inc., USA	Deepwater Developments (DW) in the Oil and Gas Industry
14 October	Prof. Jan Roháč, Czech Technical University in Prague (CTU), Czech Republic	Progress in Inertial Navigation Technology
18 November	Prof. Jørgen Juncher Jensen, NTNU AMOS and Technical University of Denmark	Conditional Stochastic Processes Applied to Wave and Wind Load Predictions
24 November	Volker Bertram, DNV GL	Energy Efficiency in Hydrodynamics, and Energy Efficiency in Machinery and Operations
25 November	Volker Bertram, DNV GL	Presentation and Writing Techniques for Engineers, and Teaching Engineering in the 21st Century
26 November	Volker Bertram, DNV GL	Unmanned Shipping, Antifouling, and (Future) Fuels and Fuel Converters
27 November	Volker Bertram, DNV GL	Some Submarine Hydrodynamics
16 December	Assistant Prof. Takenobu Toyota, Hokkaido University, Japan	Possible Formation Processes of Floe Size Distribution in the Seasonal Ice Zone

Honorary positions in universities and societies

Honorary university positions

University/Society	Person	Period	Responsibility
Aalto University, Finland	TM	Since 2014	Honorary Doctoral Degree
Dalian Maritime University, China	MB	Since 2001	Visiting Professor
Dalian University of Technology, China	OF	Since 2010	Academic Master/Visiting Prof.
Dalian University of Technology, China	TM	Since 2012	Academic Master/Visiting Prof.
Harbin Engineering University, China	OF	Since 2008	Honorary Professor
Harbin Engineering University, China	TM	Since 2009	Honorary Professor
National University of Singapore	TM	2002-2007	Keppel Professor
Technical University of Denmark	TIF	2013	Otto Mønsted Professor
University College London	OF	Since 2005	Visiting Professor
University of Surrey, UK	OT	Since 2013	Visiting Professor
University of Toronto, Canada	KYP	2015	Distinguished Lecturer
Zhejiang University, Hangzhou, China	TM	Since 2010	Visiting Professor

Honorary positions in societies

Academy	Person	Period	Responsibility
American Society of Civil Engineers	TM	Since 1995	Elected Fellow
Chinese Academy of Engineering	OF	Since 2007	Foreign Member
Croatian Academy of Sciences and Arts	OF	Since 2014	Corresponding Member
Danish Academy of Technical Sciences	JJJ	Since 1999	Member
Danish Academy of Technical Sciences	MB	Since 2001	Member
Danish Society of Naval Architecture and Marine Engineering	UDN	Since 2011	Board Member
Institute of Electrical and Electronics Engineers (IEEE)	TIF	Since 2015	Elected Fellow
Int. Assoc. of Bridge and Structural Engineers	TM	Since 2001	Elected Fellow
Int. Community for Maritime and Ocean Professionals (SNAME)	JJJ	Since 2014	Fellow
National Academy of Engineering of the USA	OF	Since 1991	Member
National Academy of Sciences of Ukraine	OT	Since 2015	Corresponding Member
Norwegian Academy of Science and Letters (DNVA)	OF	Since 1988	Member
Norwegian Academy of Science and Letters (DNVA)	TM	Since 2002	Member
Norwegian Academy of Technological Sciences (NTVA)	AJS	Since 2015	Member
Norwegian Academy of Technological Sciences (NTVA)	KYP	Since 2014	Member
Norwegian Academy of Technological Sciences (NTVA)	OF	Since 1976	Member
Norwegian Academy of Technological Sciences (NTVA)	TAJ	Since 2014	Member
Norwegian Academy of Technological Sciences (NTVA)	TIF	Since 1998	Member
Norwegian Academy of Technological Sciences (NTVA)	TM	Since 1982	Member / Vice-president 1993-1997
Offshore Energy Center, Hall of Fame, Houston, USA	TM	Since 2002	Elected
Royal Academy of Engineering, UK	TM	1995	Elected Fellow
Royal Institution of Naval Architects (RINA)	JJJ	Since 2002	Fellow
Royal Norwegian Society of Sciences and Letters (DKNVS)	TM	Since 1995	Member
Royal Norwegian Society of Sciences and Letters (DKNVS)	OF	Since 1995	Member

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