NTNU AMOS
Centre for Autonomous Marine
Operations and Systems

NTNU AMOS
Centre for Autonomous Marine Operations and Systems

Annual Report 2016

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.

excellent – generous – courageous

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

TABLE OF CONTENTS

DIRECTOR'S REPORT – MIDTERM EVALUATION

This year's annual report is prepared as a summary of the first 4 years of NTNU AMOS. The report will serve as input to the midterm evaluation of the Norwegian Research Council's Centres of Excellence award that started in 2013. The purpose of this report is to evaluate the performance during the first four years of the research period based on the activities carried out so far and to assess and possibly adjust the research plans for the second five-year period starting in 2018.

The NTNU AMOS vision, as stated in the application to the Norwegian Research Council, is the starting point and the core of the Centre, i.e.,

"To establish a world-leading research centre for autonomous marine operations and systems: To nourish a lively scientific community 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."

These ambitious scientific goals demand outstanding and long-lasting qualities, such as the *"excellent – generous – courageous"*, identified in 2013 as distinctive values both for the single NTNU AMOS research activity and for the Centre as a whole.

This vision and such values have been used as a compass and as guidance, respectively, for the management and organization of NTNU AMOS.

For the first five years, the Centre has been organized into nine projects within the following two research areas:

- Autonomous unmanned vehicles and operations.
- Smarter, safer and greener marine operations and systems.

In addition, several research projects funded by NTNU, the Research Council of Norway, the EU and industry collaborators are associated with NTNU AMOS. Since 2013, we have developed into a substantial research centre with 94 PhDs and several hundred MSc students. The core team, with 6 key scientists and 2 senior scientific advisors, has been strengthened with 23 affiliated scientists and adjunct professors. In addition, the partners consisting of NTNU, the Research Council of Norway, DNV GL, Statoil and SINTEF, and other national and international collaborators, provide substantial contributions to NTNU AMOS, while also making the research results and competencies available to society at large for value creation and knowledge-based management of the oceans.

The core budget of AMOS of approximately 600 million NOK has been expanded to more than 800 million NOK through associated projects funded by the Norwegian Research Council, the EU and industrial collaborators. The funding has supported long-term, high-potential, cutting-edge interdisciplinary research, which is crucial to the realization of high levels of autonomy for ships and ocean structures as well as unmanned robotic vehicles. Moreover, it is necessary to address the challenges associated with greener and safer maritime transport, surveillance and monitoring of the coast and oceans, offshore renewable energy, novel aquaculture structures operating in exposed sea areas, and oil and gas exploration and production in deep waters and Arctic waters.

The shift in technology towards more autonomous marine operations and systems has emerged more quickly and with greater impacts than we anticipated when we planned the research direction of NTNU AMOS in 2011-2012. As a result, the relevance and interest for NTNU AMOS have been very high from students entering into this field of education, as well as with researchers, industry, governmental agencies and politicians. This has also made NTNU AMOS a sort of *centre of gravity for fundamental research*, attracting many researchers from broader areas rather than simply being the repository of an exotic research field with narrow interest. We can already see a tremendous impact of the research carried out at NTNU AMOS. The main deliverables and outcomes from NTNU AMOS are: *competence*, in the sense of educated MSc students and PhD candidates, postdocs and researchers; new *knowledge*, in the sense of new theoretical models and methods; and *innovations*, in the sense of new products and processes that are valuable and are in use.

For NTNU AMOS and its partners and collaborators, sustainability by a holistic approach may enable the following:

- *value creation* related to the blue economy in terms of maritime, fisheries and aquaculture, oil and gas, offshore renewable energy, marine mining, tourism, coastal infrastructure;
- *addressing global challenges* related to climate change and adaption, environment, lack of energy, minerals and food; and
- *providing high standards for knowledge-based management* of the oceans and safeguarding life, environment and property.

In the following, I will emphasize some selected highlights from our research. More details are provided in a dedicated part of this report, arranged by projects.

Highlights from the first four years

Among the most relevant outcomes and scientific contributions, we can identify the following:

➔ *Autonomous unmanned vehicles and operations:*
Development of new methodology and technology and the competence of integrated marine environmental mapping and monitoring when using heterogeneous robotic technology platforms and sensors, including unmanned aerial vehicles (UAVs), unmanned autonomous ships (UAS), autonomous underwater vehicles (AUVs), remotely operated vehicles (ROVs) and ships. Higher degrees of autonomy are achieved when using an interdisciplinary approach bridging technology and science. For example, a new sensor technology using underwater hyperspectral imaging for unique classification of objects of interest has been developed. In addition, underwater hyper-redundant robots inspired by biology (snake and eel) for subsea inspection and intervention have been developed. Several successful research campaigns have been conducted in the Norwegian and Arctic areas together with end-users from marine biology, geology, archaeology and oceanography. Research results using unmanned autonomous robotic systems have been further applied by governmental agencies and industry within marine research, oil and gas, aquaculture and marine mining. The work has led to several high-quality scientific publications in international journals, conferences and featured articles in Nature, Science, Television and Radio. In addition to innovation in cooperation with governmental and industry collaborators, the following companies have been founded based on results from NTNU AMOS: Eelume (underwater hyper-redundant robots for subsea inspection and intervention), BluEye (underwater robots for the commodity market), and Norwegian Subsea (underwater instrumentation using MEMS based INS technology).

➔ *Smarter, safer and greener marine operations and systems:*
Development of new methodology and technology for guidance, navigation and control of ships in transit as well as ship manoeuvring and dynamic positioning (DP) in extreme seas and ice. In particular, the understanding of behaviour under transient conditions has been improved using hybrid control theory and new nonlinear estimation methods based on MEMS technology for distributed sensing. The research methodology is based on theoretical and numerical simulation studies in addition to model testing and extensive field testing on full-size ships. NTNU AMOS has access to several full-size ships in cooperation with industry collaborators. Moreover, the NTNU Research Vessel Gunnerus is extensively used as a research platform for new guidance, navigation and control methods in addition to hydrodynamic studies of ship response and propulsion. One highlight was the development of an open SW platform for implementation and testing of control algorithms on the Kongsberg DP system. Moreover, extensive research has been conducted on hybrid marine power plants for electrically driven ships which utilize intelligent energy management and energy storage devices such as batteries in conjunction with diesel and gas engines. Significant reductions in gas emissions can be achieved. The public interest in autonomous ships has accelerated during the last two years, with the opening of Trondheimsfjord as a new national test facility for autonomous vehicles and ships. The research done at NTNU AMOS on autonomy is both timely and highly relevant.

Numerical studies were performed to assess the challenges of greener maritime transport in a seaway. This research quantified the influence of added resistance, loss of propulsion and voluntary speed loss (as experienced by vessels in waves) on CO_2 emissions and fuel consumption. To enhance safety, our research also focuses on the occurrence and severity of abnormal, undesired events. For instance, physical tests were performed on the failure of oil-boom devices for recovery of spilled oil; advanced numerical solution strategies were proposed to handle underwater explosions and their consequences for nearby structures. Severe sea waves can induce unwanted phenomena on ships and offshore structures, such as parametric resonance (PR), water on deck (WOD), sloshing, and slamming. Reliable and efficient hydrodynamic methods have been developed for wave-body interaction problems involving WOD and PR. These studies highlighted the possible co-occurrence and mutual influence of these phenomena, as well as the importance of motion coupling and non-linear effects. Similar solution strategies are applicable to offshore renewable energy devices which are exposed to slamming, WOD and PR in high waves, depending on the platform design. Sloshing is a resonance of liquid in partially filled tanks. Sloshing induced slamming in prismatic LNG tanks is one of the most complex slamming scenarios on which dedicated experimental, theoretical and numerical studies have been based. In this case, the coupling between structural and hydrodynamic problems can result in structural stresses clearly higher than those for a rigid tank. Internal liquid resonance is also of concern for moonpools, openings used for lowering and lifting operations of subsea activities. In this case, it is an up-and-down motion of the seawater known as piston mode; damping mechanisms and coupling with platform heave motions have been studied numerically and experimentally. Sloshing resonance is also an issue for the seawater inside closed fish farms and can lead to large deformations in waves and current if the cage is flexible. Sloshing can involve strongly nonlinear waves of significant importance for structural design. Suitable control strategies need to be identified based on in-depth knowledge of the hydrodynamic loads. Increasing the size of fish farms and their move towards more exposed sea areas is an exciting topic of research. Theoretical, numerical and experimental studies have been carried out on systems with net in waves and currents, focusing on net deformations, wave-induced accelerations on the floater, mooring-line loads, fish behaviour, as well as boat operational limits. As a last note, our research also addresses the development of advanced numerical Domain-Decomposition (DD) strategies, coupling different models for an accurate and efficient solution of fluid-body interaction problems with strong nonlinear phenomena and viscous effects. Moreover, a very accurate and efficient hydrodynamic model, the Harmonic Polynomial Cell (HPC) method, has been proposed for potential-flow problems governed by the Laplace equation and further improved as well as extended to the solution of the Poisson equation, used within a Projection approach for the Navier-Stokes equations of viscous-flow problems.

It is also with great pleasure and pride that we recognize Professor Kristin Ytterstad Pettersen as one of very few researchers and as the first woman in Norway to be selected as an *IEEE fellow* (in 2017) for her contribution to the control of marine vessels and snake robots. Pettersen´s research group is world-leading on hyper-redundant robots. With support from NTNU and industry partners, she has also applied these ground-breaking research results to innovations through the spin-off company Eelume, which offers snake robots for underwater inspection and intervention. We may see a paradigm shift in underwater robotics where the field of bio-inspired structures and systems will evolve into new disciplines, such as bio-cyber-hydrodynamics, challenging the behaviour from micro to macro scales.

NTNU AMOS was also responsible for organizing the 10th IFAC Conference on Control Applications in Marine Systems, CAMS 2016 Trondheim, Norway, 13-16 September 2016. The conference was well attended with delegates from Europe, the Americas, Asia and Australia.

Together with the University of Tromsø (UiT), we have organized public exhibitions on polar night biology in Tromsø, Trondheim and other locations. The exhibition is called "Polar night – Life and light in the dead of night" and is based upon the recent discoveries and insight gained through the field campaigns carried out in Ny-Ålesund on Svalbard in recent winters.

The international recognition of the entire NTNU AMOS team, in terms of awards, honourable and trusted positions, and invited plenary lectures is remarkable and will definitely motivate and strengthen efforts and performances, in similar fashion to top sport athletes and artists – *proud yes, satisfied never*. We are by no means done. We are looking forward to the years to come.

I now take the opportunity to thank all colleagues, researchers, PhDs and MSc students, partners and collaborators for our efforts in *creating competence, knowledge and innovations for a better world.*

This is what I call impact.

Sincerely

Asgeir J. Sørensen

Professor Asgeir J. Sørensen
Director NTNU AMOS

NTNU AMOS HIGHLIGHTS FOR 2013-2016

In the application to the Research Council of Norway, NTNU AMOS targeted the education of 60 PhD candidates, 200 MSc students, and 25 postdoctoral researchers; the employment of 4 new professors; and the publication of 600 peer-reviewed conference papers and 400 journal papers, including book chapters. As described in the annual reports, these high ambitions are about to be met thanks to the strong commitment from NTNU, partners and collaborators. The following table summarizes the progress and crucial outputs of the Centre per year in terms of the Key Performance Indexes (KPIs) established at the start-up of NTNU AMOS.

	2013	2014	2015	2016	Sum
Cost - MNOK	25.2	40.7	70.1	84.8	**220.8**
Graduated PhD					
NTNU AMOS incl. CeSOS	-	13	9	14	**36**
Graduated MSc	38	88	63	81	**270**
Books	-	2	-	-	**2**
Journal papers	14	61	95	100	**270**
Book chapters	2	2	3	6	**13**
Conference papers	60	120	151	125	**456**
Keynotes	2	12	11	10	**35**
Media coverage	6	33	27	90	**156**
Start-up companies	0	1	2	0	**3**

Other highlights:

- NTNU infrastructure has been upgraded and enhanced to serve a great variety of physical investigations at NTNU AMOS; this includes the Applied Underwater Robotics (AUR-Lab) and the new Unmanned Aerial Vehicles (UAV-Lab) laboratories, hydrodynamic laboratories, and the marine machinery and hybrid power laboratories. Read more about the NTNU AMOS laboratories on the Centre's webpage
  Watch videos from relevant physical and numerical studies carried out within NTNU AMOS projects on the Centre's webpage
- Several successful research campaigns in the Norwegian oceans and the Arctic have been executed—see the NTNU AMOS annual reports 2013-2016.
- Marine UAS, an EU-funded doctoral program to strategically strengthen research training on autonomous unmanned aerial systems for marine and coastal monitoring, is being coordinated by NTNU AMOS. It is a comprehensive Marie Curie Innovative Training Network across a range of partners in several countries designed to have a high impact on the training of individual researchers and their knowledge, skills and future careers.
- Two books have been published:

- **From, Pål Johan; Gravdahl, Jan Tommy; Pettersen, Kristin Ytterstad**. Vehicle-Manipulator Systems. Springer 2014 (ISBN 978-1-4471-5462-4) 388 p. Advances in Industrial Control(1)
- **Holm, Håvard; Amdahl, Jørgen; Larsen, Carl Martin; Moan, Torgeir; Myrhaug, Dag; Pettersen, Bjørnar; Steen, Sverre; Sørensen, Asgeir Johan.** Havromsteknologi. Akademika forlag 2014 (ISBN 978-82-321-0441-3) 483 p.

- NTNU AMOS has organized several events with the aim of disseminating and promulgating its research as well as initiating new collaborations with well-established national and international researchers. The Centre's webpage provides the list of seminars, workshops and guest lectures arranged by NTNU AMOS. Special events included:

- "70 Year Anniversary Seminar and Celebration for Professors Faltinsen and Moan", organized by NTNU AMOS 19-20 May 2014 in Trondheim to celebrate its two senior scientific advisers, Professors O.M. Faltinsen and T. Moan. The event featured several former PhD candidates and well-recognized scientists in the field of marine hydrodynamics and structures as lecturers and had around 300 attendees. It also triggered the "Moan-Faltinsen Best Paper Awards" for young scientists, supported by Chinese funding and awarded annually.
- 10th IFAC Conference on Control Applications in Marine Systems (CAMS 2016), organized by NTNU AMOS 13-16 September 2016 in Trondheim.
- Together with the University of Tromsø (UiT), NTNU AMOS has organized public exhibitions on polar night biology in Tromsø and Trondheim. This exhibition is based upon the recent discoveries and insights gained through the field campaigns carried out in Ny-Ålesund on Svalbard in recent winters.

- The following companies have been founded based on results from NTNU AMOS: Eelume AS, BluEye Robotics and Norwegian Subsea AS. In addition, the key scientists Johnsen and Sørensen are co-founders of the company Ecotone AS.
- Successful establishment of the NTNU AMOS/Ocean School of Innovation for training and facilitating researcher-driven innovations and entrepreneurships. To see the measures that NTNU AMOS has taken to stimulate innovative actions, see the chapter "Innovation and training of PhD candidates" in this annual report.
- Selected awards and honours:

- IEEE fellowships: Prof. Thor I. Fossen (2016) and Prof. Kristin Y. Pettersen (2017)
- SOBENA International Award, the Brazilian Society of Naval Architecture, Marine and Offshore Engineering: Prof. Odd M. Faltinsen (2014) and Prof. Asgeir J. Sørensen (2016)
- The Society of Naval Architects and Marine Engineers (SNAME, USA) awarded the Davidson Medal to NTNU AMOS adviser Prof. Torgeir Moan (2016)

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 in the first 5-year period (2013-2017). The Centre and its staff show impressive momentum and have clearly reached the Centre's ambitious goals for the first period. 2017 is an important year for the Centre, since the research group is going through an international midterm evaluation. The purpose of the midterm evaluation is to assess the scientific quality and performance of the Centre in absolute terms and relative to the Centre's research plans. The evaluation will provide data to support the decision of the Research Council of Norway as to whether the funding and status as a Centre of Excellence (CoE) is to be continued for an entire 10-year period or to be ended after 5 years. The Board is confident that NTNU AMOS will fulfil the requirements and receive financial support for a second period (2018-2022).

At the end of 2016, NTNU AMOS employed 6 key scientists, 9 adjunct professors and 14 postdoctoral researchers. In addition, 14 scientists were affiliated with the Centre. The goal of graduating 100 PhD candidates in a 10-year period has almost been reached in four years. At the end of 2016, a headcount showed that the Centre is funding 94 ongoing PhD candidates thanks to many associated research projects. These are remarkable numbers after four years of operation. The Board met twice in 2016 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. The additional funding has been essential to reach the large number of PhD candidates and to support their research activities in experimental laboratories such as the UAV-Lab and AUR-Lab, which are key facilities to verify and validate theoretical results. At the end of 2016, 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. NTNU AMOS also hosts the MarineUAS research project, which is a comprehensive Marie Curie Innovative Training Network (ITN) funded by the European Commission. MarineUAS is contributing to training 15 European PhD candidates in Norway, Portugal, Spain, and Sweden.

The Board also wishes to note that the Centre has been instrumental in the establishment of the Ocean School of Innovation, which is a pilot programme in cooperation with the NTNU Technology Transfer. NTNU AMOS has contributed to the establishment of three spin-off companies: Norwegian Subsea, Eelume, and BluEye Robotics. Several new companies are in the pipeline, and 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. The tally for 2016 is 100 journal papers and 125 conference papers, which is quite remarkable. The Centre also graduated 14 PhD candidates by the end of 2016, and the accumulated number for 2013-2016 is 36 (2 of those financed by NTNU AMOS).

Finally, the Board looks forward to an exciting and productive second period of NTNU AMOS if the key scientists pass the midterm evaluation. We believe that a second period will result in an increased number of high-quality publications, excellent PhD candidates and high-impact postdoc projects. New insights, radical ideas and solutions will benefit research institutes and industries, provide competitive advantages and have a high impact to society. New spin-off companies will speed up the implementation of advanced technology. The Board is pleased that the NTNU AMOS School of Innovation has evolved into the Ocean School of Innovation, composed of 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.

SCIENTIFIC ADVISORY COMMITTEE

Professor Randal W. Beard

Department of Electrical and Computer Engineering,
Brigham Young University, Provo, Utah, USA

- expertise of autonomous control of micro unmanned air vehicles (UAVs) and multiple vehicle coordination and control

Professor Robert F. Beck

Department of Naval Architecture & Marine Engineering,
University of Michigan, Ann Arbor, Michigan, USA

- expertise on marine hydrodynamics, including resistance, seakeeping, maneuvering and offshore

Associate Professor Gianluca Antonelli

Department of Automatic Control,
University of Cassino and Southern Lazio, Cassiono, Italy

- expertise on underwater robotics

The Scientific Advisory Committee has met twice to evaluate and advise on the research plans of NTNU AMOS. It has given invaluable recommendations to NTNU AMOS.

ORGANIZATION, INTERNATIONAL COLLABORATORS, AND FACTS AND FIGURES

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

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, SINTEF Fisheries & Aquaculture, Dept. of Marine Technology and Dept. of Engineering Cybernetics at NTNU, SINTEF ICT, Statoil

User Panel
Members from research partners, companies and industry

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

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
- National University of Singapore
- 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
- University of Rijeka, Croatia
- Woods Hole Oceanographic Institution, USA
- University of Zagreb, Croatia
- University of Cassino and Southern Lazio, Italy

Facts and Figures

Personnel 2016

- 6 keypersons
- 9 adjunct prof./associated prof.
- 14 affiliated scientists
- 2 scientific advisers
- 4 postdocs/researchers
- 10 affiliated postdocs/researchers
- 94 PhD candidates (incl. affiliated)
- 7 visiting prof./researchers
- 2 administrative staff
- 2 management
- 2 technical staff
- 2 graduated PhD candidates financed by NTNU AMOS
- 12 graduated PhD candidates associated to NTNU AMOS (5 of those financed by CeSOS)
- 81 graduated MSc students

Revenues in 2016 (amount in NOK 1000)

- Income: 89 149 NOK
- Costs: 84 816 NOK
- Year end allocation: 4 333 NOK

Publications in 2016

- 6 book chapters
- 100 refereed journal articles
- 125 refereed conference papers
- 10 international keynote lectures

Media coverage and guest lectures at NTNU AMOS in 2016

- 18 guest lectures have been delivered at NTNU AMOS by national and international visitors.
- 90 popular science publications have been delivered in newspapers, trade journals, TV, radio, museums and online

Publications 2013-2016

- 2 books
- 13 book chapters
- 270 refereed journal articles
- 446 refereed conference papers
- 37 international keynote lectures

Graduated PhD candidates and MSc students 2013-2016

- 2 graduated PhD candidates financed by NTNU AMOS
- 34 graduated PhD candidates associated to NTNU AMOS (17 of those financed by CeSOS)
- 270 graduated MSc students

NTNU AMOS RESEARCH PROJECTS

Optimization and fault-tolerant control of offshore renewable energy systems

Project manager: Prof. Jørgen Amdahl
Scientists: Profs. Marilena Greco, Asgeir J. Sørensen, Torgeir Moan, Odd M. Faltinsen, Roger Skjetne, Mogens Blanke and Zhen Gao, Adjunct Profs. Jørgen Krokstad and Claudio Lugni, Associate Prof. Erin E. Bachynski, Dr Amir Nejad, Dr Bjørn Skaare (Statoil)
PhD candidates: Emil Smilden, Jan-Tore Haugan Horn, Stian Sørum, Wilson I. Guachamin Acero, Zhengshun Cheng, SeongPil Cho, Mahdi Ghane, Lin Li, Ling Wan, Yuna Zhao, Valentin Chabaud, Maxime Thys, Lars Ove Sæther
Website: www.ntnu.edu/amos/project-1

Offshore renewable energy, notably that extracted from wind, is expected to play an increasingly important role in meeting the demands for clean energy and energy security. Whereas fixed offshore wind turbines in shallow waters are now considered established commercial technology, major research challenges still impede the large-scale application of fixed and floating wind turbines at greater depths. Further research is required to reduce the costs to competitive levels. To address fluid-dynamic loads/motions and structural response in severe waves, wind and currents, new mathematical models must be developed for the design, analysis, control and optimization of wind turbine and wave energy converter parks under both ordinary and fault conditions. Floating wind turbines will exhibit a strong nonlinear behaviour with large motions, global hydro-elasticity, parametric resonances, and blade vibrations affecting the overall integrity of the structure, the drive-train and the energy harvesting efficiency. Bottom fixed turbines may exhibit hydro-elastic behaviour. Experimental and in-service experiences are required to validate wind turbine technology. The optimal design of wind and wave energy facilities requires analyses that integrate hydrodynamics, mechanical engineering, structural mechanics, electrical engineering and automatic control.

Associated research projects

Wind turbines in fault conditions: fault detection/diagnosis and fault tolerant control
Project manager: Prof. Torgeir Moan
Involved PhD candidates: 2

The deployment of larger scale wind turbine systems, in particular, offshore, requires well-organized operation and maintenance strategies to make them as competitive as classical electric power stations. Maintenance and repair costs constitute an important portion of the operating costs of a typical wind turbine. These costs are more significant for offshore turbines due to limited weather windows compared to onshore turbines. In this regard, a good understanding of wind turbine behaviour under fault and shutdown conditions and the ability to detect, isolate, and estimate faults and accommodate new changes is crucial. Former PhD candidates in CeSOS have studied long-term response analysis of wind turbines for different faults and shutdown conditions. The current focus is on fault detection/diagnosis and fault-tolerant control of floating wind turbines, especially for faults in two main components: the drivetrain and the blade pitch actuators.

Analysis and design of combined wind- and wave energy concepts
Project manager: Prof. Torgeir Moan
Involved PhD candidates and postdocs: 1 postdoc and 1 PhD candidate

The combined wind/wave energy concepts Semi-submersible Flap Combination (SFC) and Spar-Torus (STC) were developed by CeSOS under the EU MARINA Platform Project with the objective of utilising the synergy between wind turbines and wave energy converters. The project consists of extensive numerical and experimental studies of the two concepts and development of a patent for the STC concept.

Analysis of marine operations relating to wind turbine installation
Project manager: Prof. Torgeir Moan
Involved PhD candidates: 3

Offshore wind turbines (OWTs) need to be installed duly considering equipment, installation procedures, and operational limits within the installation procedures. These limits are required to ensure the safe execution of marine operations and need to be practical for use on-board by personnel for decision making. The operational limits for the installation of various offshore wind turbine components using a floating installation vessel must be established by applying a generic and systematic response-based methodology.

Main results

Wind turbines are dynamically sensitive structures with resonance frequencies close to or even within the excitation frequency of the environmental loads, see Figure 2, making them sensitive to the damping in the system. The design of bottom-fixed wind turbine systems, including the tower and substructure, is therefore generally driven by fatigue considerations rather than extreme loads. Alternative hydrodynamic models were compared for a large-diameter monopile foundation. It was found that higher order wave loads contribute only slightly to the fatigue damage; however, it is important to consider wave diffraction. **Control system algorithms based on reduced-order models** of bottom-fixed wind turbines may be used to improve the overall performance regarding power harvesting and maintaining structural reliability. A model to be used in control applications was presented and verified in [P1.R1]. The proposed low-fidelity model showed good agreement with the detailed nonlinear model.

Faults in gearboxes and blade pitch actuators are among the most safety-critical elements of wind turbines. **Fault detection and estimation in gearboxes** was investigated for a 5-MW reference turbine installed on the OC3 Hywind Spar concept [P1.R2]. A decoupled approach, see Figure 3 left, was used to obtain the dynamic response. Faults in the main shaft bearing were treated using statistical change detection. The Cumulative Sum Method was

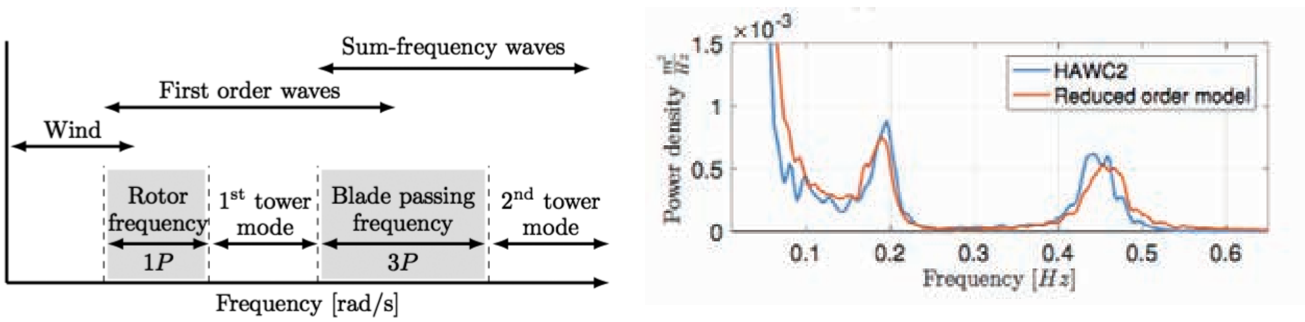


Figure 2: *Left: The most important response and load frequency bands. Right: The tower top displacement spectrum for the full FEM method and the reduced-order model.*

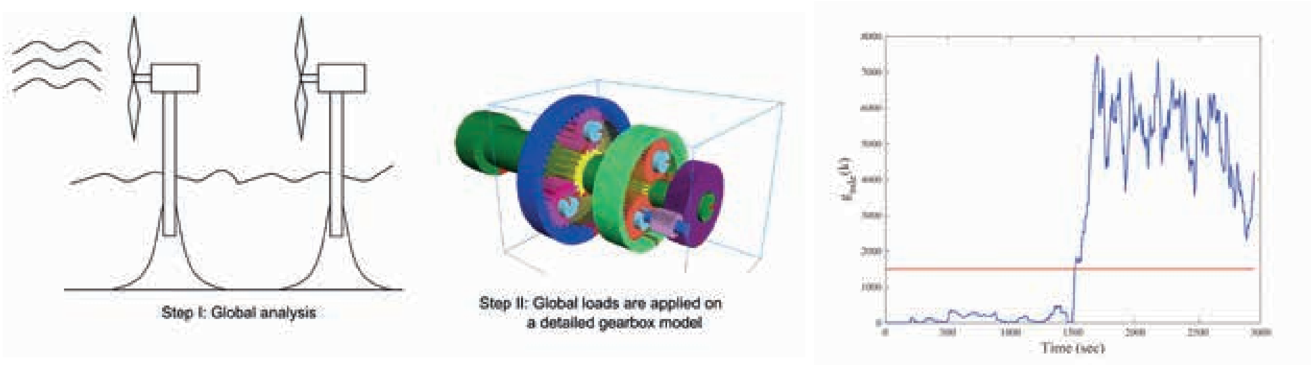


Figure 3: *Left: The global analysis and gear box model used in the de-coupled approach. Right: GLRT decision function history - fault occurrence at approximately 1500 s.*

applied when the fault magnitude was known, and the Generalized Likelihood Ratio Test (GRLT) was implemented in the case of an unknown fault magnitude. Figure 3 right shows the decision function history of a GLRT algorithm using the maximum likelihood estimator to estimate the unknown wear severity. It was shown that the proposed method could detect the assumed wear quickly and robustly even for a wear severity range that is very low according to operational standards, e.g., ISO 10816-1.

The detection of faults in blade pitch sensors and actuator and fault-tolerant control may be based on a Kalman filter based and on the residual generation and evaluation method [P1.R3]. Two fault-tolerant control actions were suggested: signal correction for sensor faults and shutdown for actuator faults. Actuator faults are safety critical, leaving the pitch actuator inoperable regardless of the controller command. A fault-tolerant control strategy that was proposed for the blade pitch system was found to effectively address multiple generated faults in the blade pitch system.

The combined wind and wave energy converters STC and SFC, see Figure 4 left, were developed by CeSOS under the EU FP7 Marina Project. **Water-entry, water-exit and water-on-deck events for the STC concept** were observed during survivability model tests (at Marintek and at CNR-INSEAN [P1.R4]). The spar and torus were connected by load cells to measure the global loads between them induced by the slamming forces on the bottom of the torus. A numerical method based on a blended station-keeping potential-flow solver was developed to simulate these nonlinear phenomena. The comparisons between the numerical solver and model tests are globally satisfactory in terms of platform motions, mooring-line tensions, and the occurrence and features of water-entry, water-exit and water-on-deck events (Figure 4).

According to the investigation, the water on deck is very effective in reducing the double-wave frequency component of the surge, heave and pitch motions for sufficiently large incident-wave periods and in reducing the mean surge and pitch motions close to the heave resonance. The slamming events have a limited effect on the body motions, but they induce large loads between the spar and the torus.

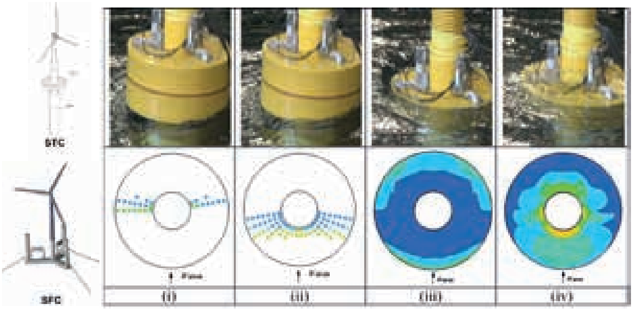


Figure 4: Left: Combined wind-wave energy converters. Right: water entry (i, ii) and water on deck (iii, iv) in steep regular waves (with height H=9 m and period T=15 s at full scale). Top: experimental snapshots (the incident wave travels from left to right). Bottom: Numerical slamming pressure (i,ii) and level of water on the deck (iii, iv), with increasing values from blue to red. Time increases from left to right.

The severe slamming suggests that it should be considered to place the STC concept in survival mode with the torus submerged in extreme seas. The SFC survived severe storms by parking the wind turbine and allowing the WECs to rotate freely. The WECs increased the power absorbed by the wind turbine and added absorbed wave power slightly, but they did not significantly affect the structural responses in the tower and mooring lines.

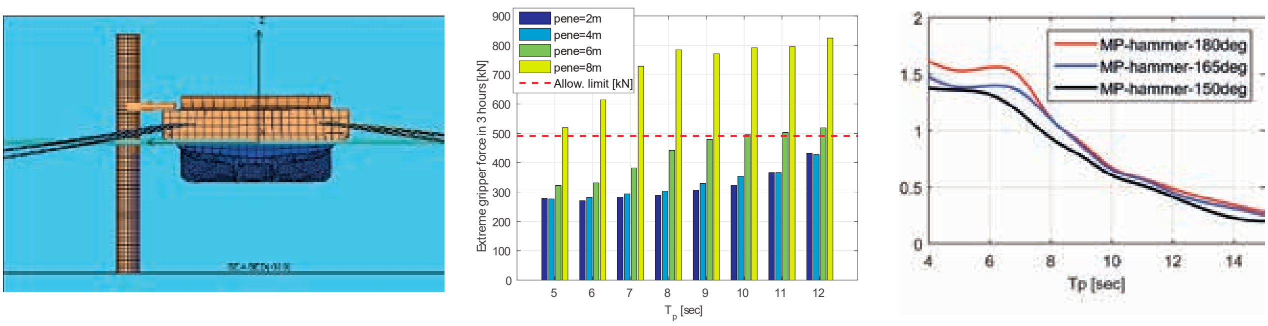


Figure 5: Left: Coupled dynamic model of a floating installation vessel and a monopile; Middle: Assessment of characteristic values of gripper dynamic contact forces for different seabed penetrations; Right: Operational limits in terms of allowable limits of sea states for different vessel heading angles.

A generic and systematic **methodology for the assessment of operational limits** of marine operations using response-based criteria was developed. The limits were established based on the dynamic responses of the systems obtained by numerical time-domain simulations of the actual marine operations, including non-linear and non-stationary features of the stochastic response processes. The operational limits obtained are expressed in terms of allowable environmental conditions and can be used for weather window analyses. The methodology was applied to analyse a novel installation procedure for an OWT tower and rotor nacelle assembly (RNA) [P1.R5]. Numerical models of the monopile (MP), the transition piece (TP), the OWT tower and the RNA (see Figure 5 left) were used to simulate the actual installation activities such as MP lowering, MP initial hammering process and TP mating. By comparing characteristic values of the dynamic responses (Figure 5 middle) for any sea state with the corresponding allowable limits, it was possible to conduct a backward derivation of the corresponding sea state parameters. These resulting operational limits (Figure 5 right) may be used to plan operations as well as to support on-board decision making.

Real-time hybrid model (ReaTHM®) testing of offshore wind turbines is necessary to address the scaling (Froude-Reynolds mismatch) and practical (wind generation and measurement) challenges associated with model tests of floating wind turbines in an ocean. In essence, the platform motions are measured and passed to the numerical simulator, and actuators apply appropriate aerodynamic/generator forces and moments based on the results of the numerical simulations. Within the NOWITECH project, a semi-submersible platform carrying a 5 MW wind turbine was tested at 1:30 scale in the Ocean Basin; refer to Figure 6. This extended the ReaTHM testing concept to 5 degree-of-freedom aerodynamic/generator loads using a novel actuation system [P1.R6]. For the response frequencies of interest, the undesired damping effects of the hybrid system were found to be small, and the coupling between wind and wave loads was successfully actuated.

Selected references:

P1.R1. **Smilden, Emil; Horn, Jan-Tore H.; Sørensen, Asgeir Johan; Amdahl, Jørgen.** Reduced Order Model for Control Applications in Offshore Wind Turbines. IFAC-PapersOnLine 2016 ;Volume 49.(23) p. 386-393

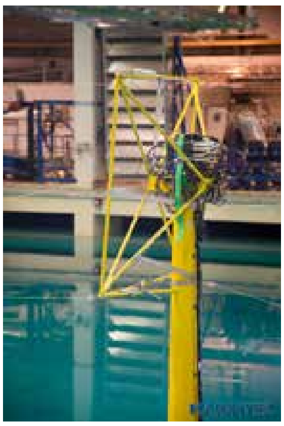
P1.R2. **Ghane, Mahdi; Rasekhi Nejad, Amir; Blanke, Mogens; Gao, Zhen; Moan, Torgeir.** Statistical fault diagnosis of wind turbine drivetrain applied to a 5MW floating wind turbine. Journal of Physics, Conference Series 2016 ;Volume 753. p. 052017

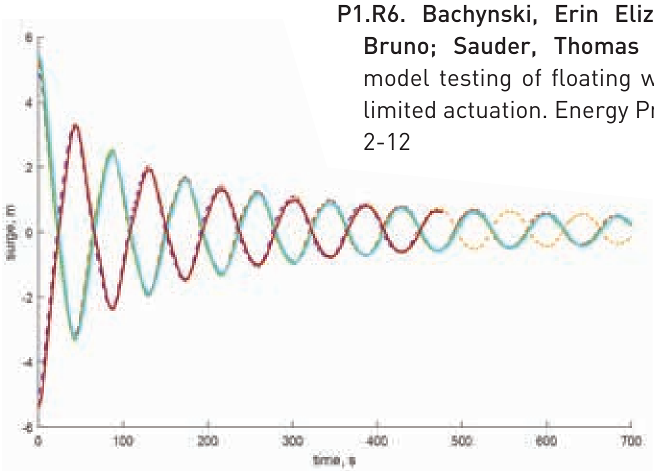
P1.R3. **Cho, Seongpil; Gao, Zhen; Moan, Torgeir.** Model-based fault detection of blade pitch system in floating wind turbines. Journal of Physics, Conference Series 2016 ;Volume 753. p.092012

P1.R4. **Wan, Ling; Greco, Marilena; Lugni, Claudio; Gao, Zhen; Moan, Torgeir.** A combined wind and wave energy-converter concept in survival mode: numerical and experimental study in regular waves with a focus on water entry and exit. Applied Ocean Research 2016 ;Volume 63. p. 200-216

P1.R5. **Li, Lin; Guachamin Acero, Wilson Ivan; 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-Transactions of The Asme 2016 ;Volume 138.(4) p. 041902

P1.R6. **Bachynski, Erin Elizabeth; Chabaud, Valentin Bruno; Sauder, Thomas Michel.** Real-time hybrid model testing of floating wind turbines: sensitivity to limited actuation. Energy Procedia 2015 ;Volume 80. p. 2-12





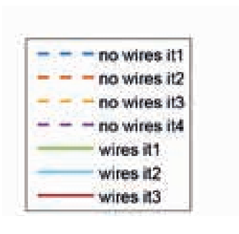
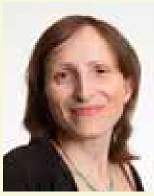


Figure 6: Left: "Rotor" of the 5 MW wind turbine, showing the lines (connected to motors) for actuating aerodynamic loads. Right: decay tests in surge without the hybrid system and with the hybrid system in the "following" mode.

Intelligent offshore aquaculture structures



Project manager: Prof. Marilena Greco
Scientists: Profs. Asgeir J. Sørensen, Jørgen Amdahl, Oleksandr Tymokha, Odd M. Faltinsen and Trygve Kristiansen
PhD candidates: Yugao Shen, Pål T. Bore, Ida M. Strand, Peng Li, Zhao He, Mohsen Bardestani
Website: www.ntnu.edu/amos/project-2

There is significant potential for increasing marine food production by moving marine fish farms to more exposed areas. The fish farms would be, however, subject to more energetic waves and stronger currents. Well boats will also increase in size, with dimensions comparable to the fish farms, and their operational limits must be identified to ensure safety. New designs for fish farms in exposed sites will appear. The importance of marine technology will consequently increase. Damage to and collapses of floating fish farms have led to fish escaping and thereby major economic losses. Damage can be caused by operational failures, the breaking of mooring lines, anchor pull out or contact between chains or ropes with nets. Escaped farmed salmon may bread with wild salmon and lead to genetic pollution of the wild fish. Salmon lice is another concern and has initiated investigations at NTNU AMOS in cooperation with SINTEF Fisheries and Aquaculture and industry partners on using a membrane structure as cover material for a cage – called a closed flexible cage. The membrane structure can be deformed considerably in current; another issue is wave-induced sloshing inside the cage. Mathematical models combining hydrodynamics and structural mechanics and accounting for the internal water flow are under development. Control methods of the flow inside the cage are also considered using distributed flow control. As alternatives, designs of closed fish farms with more rigid behaviours, e.g., being made of fibreglass, have been proposed. Circular net cages with elastic floaters can also deform significantly in current, and their netting may have 10 million meshes, which limits CFD and complete structural modelling.

Associated projects and programmes

Closed flexible cages (CFC)

Project manager: Pål Furset Lader (SINTEF Fisheries and Aquaculture)
NTNU AMOS affiliated scientists: Profs. Asgeir J. and Odd M. Faltinsen
Involved PhD candidates: 1
Website: www.sintef.no/en/projects/external-sea-loads-and-internal-hydraulics-of-clos

This project has formally ended, but its research activities continue through the funding of on-going PhD work also connected with NTNU AMOS. The focus is on the assessment of closed flexible cages (CFCs) as fish farm design alternatives. Challenges to CFCs concern the limited knowledge about how aquaculture systems with CFCs will respond to external sea loads because very few ocean structures exist with large, heavily compliant submerged components. A closed bag will experience an increase in hydrodynamic drag compared to a net-based structure. In addition, the flexibility and deformation of the bag is closely coupled to the hydrodynamic forces. In addition to the external forces and deformation issues, the enclosed body of water must be properly maintained to ensure good water quality, fish welfare and high biosecurity.

SFI EXPOSED

Programme manager: His Vanhauwaert Bjelland (SINTEF Fisheries and Aquaculture)
NTNU AMOS affiliated scientists: Profs. Jørgen Amdahl, Odd M. Faltinsen and Marilena Greco
Involved PhD candidates: 1
Website: http://exposedaquaculture.no/en

EXPOSED is a Centre for Research-based Innovation (SFI) and develops knowledge and technologies for robust, secure and efficient aquaculture at exposed locations. The EXPOSED Centre attempts to exploit Norway's strong position and expertise in maritime sectors, such as aquaculture and offshore, to enable safe and sustainable seafood production in vulnerable coastal and marine areas. Technical innovations, such as autonomous systems, offshore structures and vessels, are required to maintain production under all conditions and enable more robust, secure and controlled operations. The centre integrates six research areas, four focusing on technological innovations for safe and reliable aquaculture operations and two focusing on key requirements for sustainable production. The EXPOSED Centre brings together global leading salmon farmers, key service and technology providers, SINTEF Fisheries and Aquaculture and other strong research groups, including NTNU AMOS. The centre budget is composed of approximately 50% from the Research Council, 25% from industry partners and 25% from research partners.

Main results

Some of the following topics started within the SFI CREATE and then continued in NTNU AMOS through the supervision activity of the NTNU AMOS Scientific Advisor Prof. Odd M. Faltinsen.

The dynamic behaviour of a fish farm under real-world conditions represents a complex scenario, which, for **the floater**, can involve large relative vertical motions, high local accelerations, hydroelastic effects and wave structure interaction with local wave overtopping and out-of-water phenomena (left of Figure 7). An experimental (at MC Lab) and theoretical study examined a moored isolated floater in regular waves. Hydroelasticity matters for an elastic floater, with relevant 3D effects in the wave-induced loads. A weak-scatterer seakeeping solver could only partially explain the nonlinearities in the measured vertical accelerations, which were also found to be important for a nearly rigid floater [P2.R1]. This emphasises the need for a 3D fully nonlinear formulation of the problem including viscous effects due to flow separation.

Large relative vertical motion between the floater and the sinker tube and the elastic behaviour of the net structure can lead to **snap loads** in fish farm nets. 2D experimental and theoretical studies on a section of a floater with a net structure and sinker tube showed large snap loads in regular waves and uniform current. This confirms that they represent a possible cause of fish-farm rupture and fish escape and thus highlights the need to consider cyclic snap loading within net-structure failure analysis.

The mean loads dominate with respect to the dynamic loads for **the mooring-line system**. This was assessed by performing a parametric experimental (at MC Lab) and numerical investigation on a simplified model with the main components of an aquaculture structure in waves and current [P2.R2]. Numerically, the motions of the net cage, bottom weights (replacing the bottom ring), floater and moorings were solved as a coupled system, therein using a truss structural model for the net cage and moorings and a screen model for the hydrodynamic, viscous forces on the net cage. At any time step, first, the hydrodynamic forces on the net and the elastic floater are calculated. Next, a linear system of equations for the tensions in all the trusses is solved. Then, the new configuration of the fish-farm system becomes available by using Newton's second law, with a lumped-mass approach for the net cage nodes.

Fish typically occupy 2.5% of the cage volume, and their presence and motion can affect the mooring-line loads in waves and current. Experiments (at MC Lab, centre and right of Figure 7) with artificial and live fish in a cage showed that real fish are more relevant than artificial fish. In current, they tend to be pressed towards the net (left of Figure 8), leading to a higher local solidity ratio and increasing the mooring-line loads by 10% to 28%, in the studied cases, with respect to a cage without fish. The solidity-ratio effect was quantified by performing numerical studies with an increased solidity ratio in the net-cage region where the real fish were pressed in the experi-

Figure 7: Left: overtopping and out-of-water event for the floater of a fish farm without a net in a storm (photo: Marius Dahle Olsen). Centre and right: experiments on a net cage with 9 artificial fish (centre) and with 814 real fish (right) in regular waves and current.

ments (centre of Figure 8). In waves, the fish tend to dive to the cage bottom, leading to a higher bottom weight for the net (right of Figure 8).

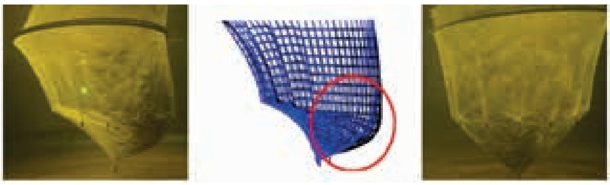


Figure 8: Real fish inside a cage. Left: experiments in current (coming from the left). Centre: numerical results in current with modelling of the fish effect as an increased solidity ratio in the net part indicated by the red circle. Right: experiments in regular waves (coming from the left).

In exposed sea areas, periodic **well-boat operations** are expected to be performed under more severe weather conditions. Fish farms and well boats will be larger and of similar size, and the well boat may threaten the structural integrity of the system during harvesting operations when it is directly moored to the fish farm (left of Figure 9). Therefore, it is necessary to set the operational limits for this operation. An efficient and reliable numerical method was developed and used for systematic simulations of the coupled well boat-fish farm system in regular waves and current. From the analysis, the well boat will significantly increase the peaks of mooring tensions and the deformation of the floating collar. The maximum stress along the floater may exceed the yield stress even in not severe sea states (right of Figure 9).

Simulations in irregular waves and strong current highlighted the occurrence of large negative tensions in the net near the contact with the floating collar. This suggests possible snap loads and confirms the need to investigate their relevance in real scenarios.

Closed fish farms represent a good solution for preventing environmental pollution and fish escape and mitigating risks for wild fish ecosystems and problems of salmon lice. However, **nonlinear sloshing** of the internal seawater can be excited. This jeopardises the structural integrity as well as the wellness of the fish. To prevent sloshing, suitable control strategies need to be identified, therein requiring reliable and efficient modelling of hydrodynamic loads. Using the multimodal method, a nonlinear mathematical model was derived for containers with circular (annular) cross-sections at the free surface for the prediction of nonlinear steady-state resonant waves [P2.R3]. The model admits semi-analytical solutions, which are well suited for parameter studies as well as for the development of control strategies. The method has been successfully validated against experiments by Royon-Lebeaud et al. (2007) for a tank in forced harmonic sway, with good estimates of stable steady-state planar and swirling wave occurrence being obtained (left of Figure 10). Swirling is a progressive wave motion in the angular direction (rotary waves) that leads to large water run-up along the vertical sides (right of Figure 10). This leads to a force component perpendicular to the forced-oscillation direction of similar magnitude as in the excitation direction. The proposed method was used to examine the effects of an arbitrary 3D periodic forcing associated with external seaway loads. First, in the literature, the

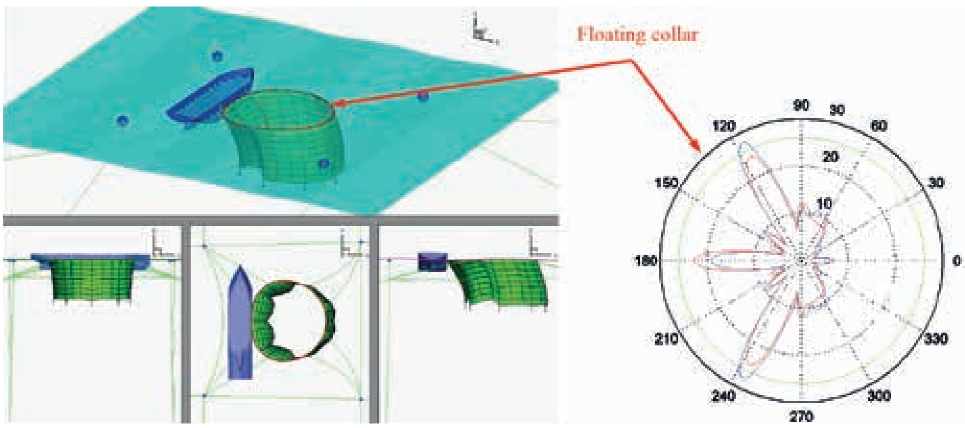


Figure 9: Coupled fish farm-well boat system in waves and current (left) and stress distribution along the floating collar (right) for current velocity = 0.6 m/s, wave steepness = 1/60 and wave period = 6 s (red line) and 9 s (blue line). The green line represents the yield stress of the floater (high-density polyethylene).

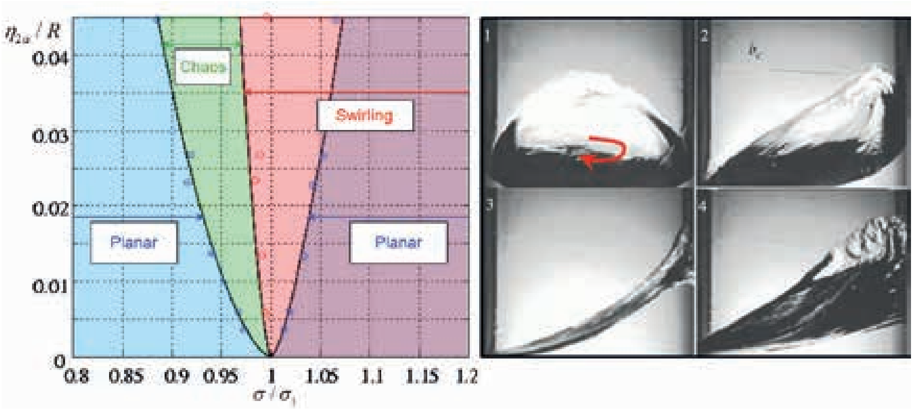


Figure 10: Partially filled, upright circular cylindrical tank with radius R forced in harmonic sway with amplitude η_{2a} and frequency σ. Left: Stable resonant sloshing waves and chaos from theoretical predictions. The blue and red symbols are experimental boundaries for planar and swirling waves, respectively, by Royon-Lebeaud et al. (2007). σ_1 is the lowest natural frequency. Right: experimental images of a swirling wave, with the arrow indicating the motion direction of the wave. The time increases from 1 to 4.

steady-state resonant waves were classified, therein highlighting that stable resonant sloshing is always of the swirling type. The so-called critical water depths, where very violent wave motion will occur, were also identified.

Closed Flexible Fish Cages (CFFCs) can experience large deformations due to current loads. To ensure a proper behaviour, fundamental knowledge is needed. Model tests were performed in steady current for different filling levels of the CFFC [P2.R4]. The analysis highlighted an increase in the global drag force with decreasing filling level. This is due to the occurrence of large "parachute"-shaped deformations of the bag, which strongly depend on the filling level of the internal water (Figure 11). A 2D model is under development for the coupling between the internal liquid and the deformable structure in waves, where both analytical and numerical methods will be used and viscous effects can be neglected.

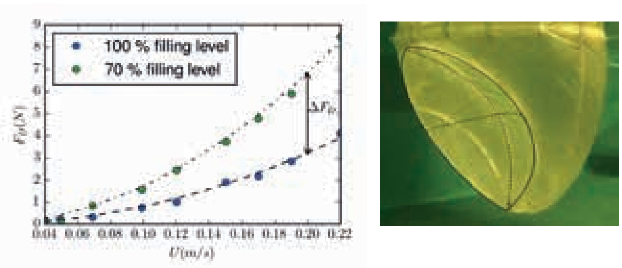


Figure 11: Experiments on a CFFC in steady current with speed U. Left: global drag. Right: deformed bag for 70% filling level at U=0.12 m /s.

Selected references:

P2.R1. Li, Peng; Faltinsen, Odd Magnus; Lugni, Claudio. Nonlinear vertical accelerations of a floating torus in regular waves. Journal of Fluids and Structures 2016 ;Volume 66. p. 589-608

P2.R2. Kristiansen, Trygve; Faltinsen, Odd Magnus. Experimental and numerical study of an aquaculture net cage with floater in waves and current. Journal of Fluids and Structures 2015 ;Volume 54. p. 1-26

P2.R3. Faltinsen, Odd Magnus; Lukovsky, Ivan A; Timokha, Alexander. Resonant sloshing in an upright annular tank. Journal of Fluid Mechanics 2016 ;Volume 804. p. 608-645

P2.R4. Strand, Ida Marlen; Sørensen, Asgeir Johan; Volent, Zsolt; Lader, Pål. Experimental study of current forces and deformations on a half ellipsoidal closed flexible fish cage. Journal of Fluids and Structures 2016 ;Volume 65. p. 108-120

Autonomous unmanned vehicle systems

Project manager: Prof. Tor Arne Johansen
Scientists: Profs. Thor I. Fossen, Kristin Y. Pettersen and Lars Struen Imsland, Adjunct Profs. Karl Henrik Johansson and Kanna Rajan, Associate Prof. Edmund Brekke, Dr Morten Breivik
Postdocs: Dr Mark Haring, Dr Giorgio Kwame Kufoalor
PhD candidates: Frederik Stendahl Leira, Claudio Paliotta, Artur Zolich, Albert Sans Muntadas, Krzysztof Cisek, Anders Albert, Sigurd M. Albrektsen, Siri H. Mathisen, Håkon H. Helgesen, Andreas L. Flåten, Erik F. Wilthil, Bjørn Olav H. Eriksen, Elias Bjørne
Website: www.ntnu.edu/amos/project-3

This project is dedicated to the study of fundamental challenges that need to be solved to enable fully autonomous vehicle systems to support marine operations. This provides a common foundation for autonomous unmanned underwater vehicles, surface vessels, aerial vehicles, and other systems such as floating structures, offshore robots, and nodes of a mobile sensor networks.

The outcomes are expected to be robust ad hoc mesh network architectures for communication between heterogeneous vehicle systems and sensor networks, therein being capable of handling degraded and time-varying radio and hydro-acoustic communication channels in the context of delay-tolerant networking. Nonlinear observer theory is expected to lead to new efficient algorithms for the sensor fusion of inertial, magnetic, range/position, velocity, and imaging sensors. Target detection and tracking, based on imaging sensors, are important elements of the research. Further outcomes are new methods for multi-vehicle distributed missions and path planning, using optimization and heuristic search methods in combination with sensory and estimation information, terrain models, and simulations of vehicles and communication channel losses. These developments are accompanied by new architectures and algorithms for fault-tolerant and intelligent command execution in autonomous unmanned vehicles, including obstacle avoidance and re-configurable control. The above research outcomes will be experimentally demonstrated in collaboration with NTNU AMOS projects 4 and 5.

Associated research projects and programmes

Innovative training network on autonomous unmanned aerial systems for marine and coastal monitoring (MarineUAS)
Project manager: Prof. Tor Arne Johansen
Funding: European Union (H2020 – Innovative Training Network)
Involved PhD candidates: 5
Website: www.marineuas.eu

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

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 (UASs) 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. UASs offer various 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 impacts on the environment.

MarineUAS recruits and trains 15 doctoral fellows via a specially developed and unique training programme designed based on the EU Principles for Innovative Doctoral Training. The project collaborators are University of Porto, Instituto Superior Tecnico Lisbon (IST), University of Sevilla, Linköping University, Honeywell, Maritime Robotics, NORUT Tromsø, and Center for Advanced Aerospace Technology (CATEC).

Multi-stage global sensor fusion for navigation using nonlinear observers and eXogenous Kalman filter
Project manager: Prof. Tor Arne Johansen
Funding: Research Council of Norway (FRINATEK)
Involved PhD candidates and postdocs: 1 PhD candidate and 1 postdoc

Reduced cost, miniaturization, and increased availability of advanced sensor systems represent major driving forces and enablers for new technologies, products and services. GPS, cameras, inertial measurement units, pressure sensors and radio/network position are ubiquitous and are widely embedded in devices today.

At the core of these systems lies advanced software that translates the raw measurements into accurate and reliable estimates of position, velocity and attitude. This process depends on mathematical models of the sensor systems and the user (e.g., vehicle model) and is called navigation sensor fusion. To ensure the safety and reliability of emerging applications, the project focuses on more robust and reliable processing architectures, algorithms and software for navigation sensor fusion. A main hypothesis is that the navigation sensor fusion can be solved with high accuracy, robustness and reliability using estimators and observers that have individual strong global properties. The underlying theoretical platform for the project is the use of such estimator modules in cascade and weak feedback interconnections that ensure that the total system inherits their strong global stability properties.

The project funds two postdoctoral researchers and one doctoral candidate.

Sensor fusion and collision avoidance for autonomous surface vehicles (AutoSea)
Project manager: Associate Professor Edmund Brekke
Funding: Research Council of Norway (MAROFF), Kongsberg Maritime, DNV GL, Maritime Robotics
Involved PhD candidates and postdocs: 3 PhD candidates and 1 postdoc
Website: www.ntnu.edu/amos/autosea

The project vision is for the Norwegian maritime industry and researchers in collaboration with international partners to attain world-leading competence and knowledge in the design and verification of methods and systems for sensor fusion and collision avoidance for autonomous surface vehicles (ASVs). This knowledge-building project funds 3 doctoral fellows and 1 postdoc.

The research partners develop and evaluate such methods and systems in compliance with the maritime anti-collision regulations (COLREGS), therein utilizing the fusion of data from radar, AIS, IR, LIDAR, camera, IMU, GPS, etc. In addition to enabling commercial ASVs, the results can be used to enhance decision support systems for humans on manned vessels. The project will also provide a solid foundation for independent third-party verification of autonomous marine technology.

Autonomous unmanned aerial system as a mobile wireless sensor network for environmental and ice monitoring in Arctic marine operations
Project manager at NTNU: Prof. Tor Arne Johansen
Funding: Research Council of Norway (MAROFF innovation project), Radionor Communications, Maritime Robotics, Kongsberg Seatex
Involved PhD candidates: 4

This innovation project is funded by the Research Council of Norway (MAROFF) and is a collaboration between Radionor Communications, Kongsberg Seatex, Maritime Robotics and NTNU AMOS.

For future oil exploration and ship traffic in the Arctic, the monitoring of environmental and ice conditions will be critical for ensuring safety. Large manned aircraft and ships, satellites, weather buoys and some stationary oil installations today perform remote sensing of oceans with sensors / sampling methods. Of these systems, only satellite-based systems and military aircraft are effective at monitoring remote marine areas in the Norwegian economic zone. For commercial operations in areas highly remote to the infrastructure in the Arctic, the transport of airplanes and crews to and from operational areas dominates cost. In these areas, Unmanned Aerial Systems (UASs) have the potential to achieve significant cost savings and increased availability.

The key research questions are meant to facilitate the application of reliable and safe UAS technology used as a mobile wireless sensor network for environmental and ice monitoring to increase safety and efficiency in arctic offshore operations. In particular, this includes

- Long-range wireless broadband UAS data-links that are not dependent on satellites
- Distribution and presentation of sensor data for ice and environmental management in complex vessel operations in Arctic environments
- Redundant navigation systems for UASs that are not dependent on satellite navigation systems

Networked OCEAN
Project manager at NTNU: Prof. Tor Arne Johansen
Funding: EEA bilateral project between Norway and Portugal
Involved PhD candidates: 2
Website: http://networkedocean.lsts.pt
Video from the project: http://maritimerobotics.com/wp-content/uploads/2017/01/unmanned_future.mp4

The project concerns the development and demonstration at sea of a networked vehicle system for persistent communications and data collection in remote oceanic areas. The system is composed of a long-endurance autonomous surface vehicle (ASV), long endurance autonomous underwater vehicles (AUVs), long-range unmanned air vehicles (UAV), and control stations. The ASV is both a communications hotspot and a docking base (for AUVs), operating 24/7 in remote ocean areas. The ASV supports smart routing protocols for direct communications via persistent UAV relays or delayed data transfer to control stations. The control stations provide advanced planning and execution control capabilities as well as facilitates the dissemination of data. The system supports inter-operability protocols to allow expansion to vehicles from third parties.

The project builds on the technological, scientific and operational experience of a consortium consisting of FEUP (leader), IPMA, and the Portuguese Navy from Portugal; KTH from Sweden; and NTNU AMOS, Maritime Robotics, Radionor Communications and FFI from Norway.

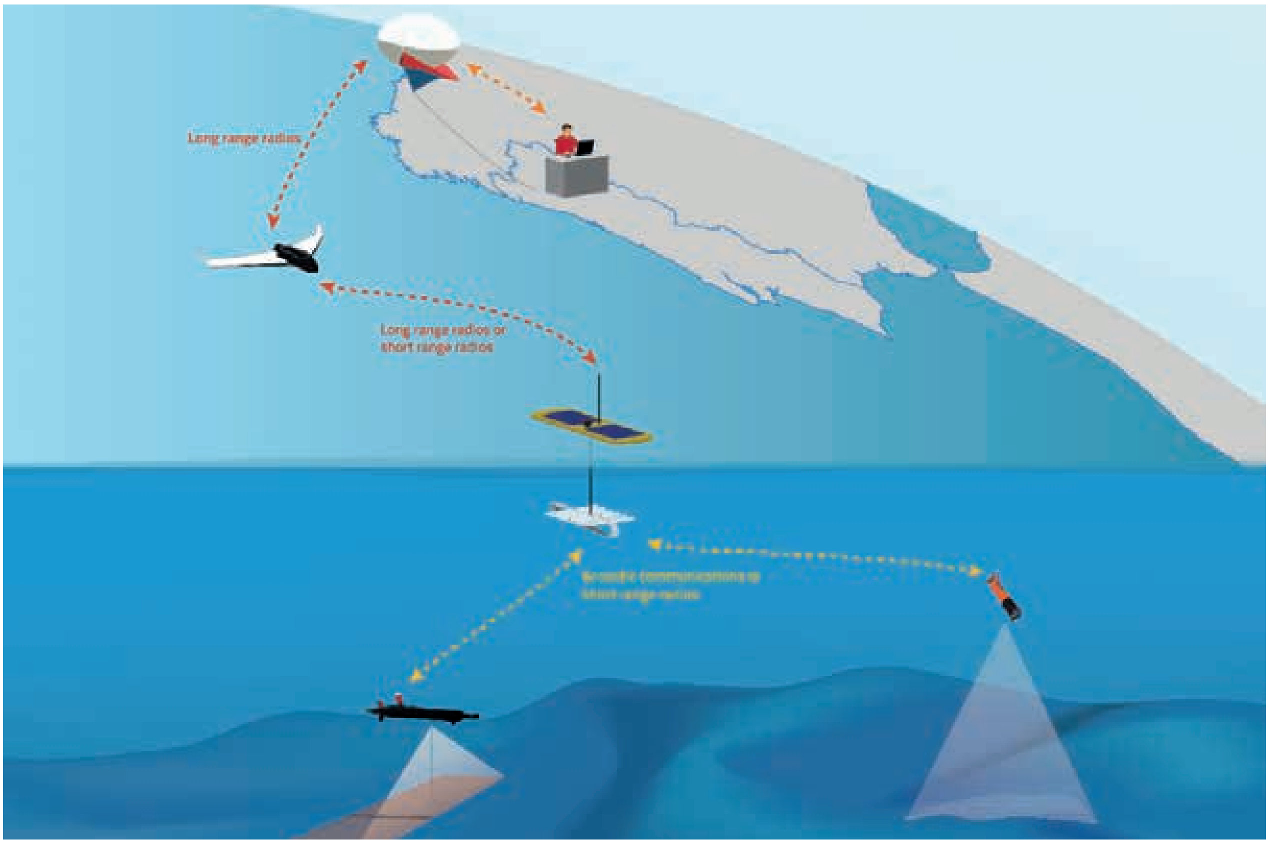


Figure 12: The figure illustrates the NetOcean concept of operation, where unmanned aerial and surface vehicles function as relay nodes in a communication network connecting underwater vehicles to a shore operation centre.

Main results

Networked OCEAN
Key scientist: Prof. Tor Arne Johansen

The NetOcean project was run in 2016 with several field experiments, leading to a two-week intensive testing period from 29 August – 9 September in the fjord between Agdenes and Trondheim. The field tests included vehicles from NTNU, KTH, University of Porto and Maritime Robotics. The team demonstrated at sea a networked vehicle system for persistent communications and data collection in remote oceanic areas, therein focusing on

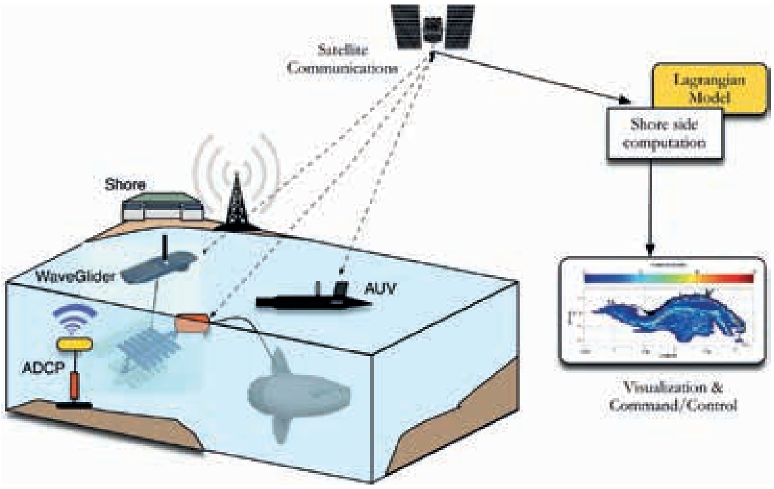
1. Autonomous networking capabilities for an eco-system of underwater, surface and air vehicles in an underwater target (fish) tracking scenario
2. Transparent inter-operability of underwater and radio communication networks
3. Incorporation of human supervision in mission planning and execution over intermittent communication networks
4. Autonomous launch of AUVs from an autonomous surface vehicle
5. Inter-operability framework allowing for the expansion of the system with vehicles provided by third parties

Integrated monitoring of sunfish behavior in space and time using satellites, UAVs, ASVs and AUVs
Scientist: Adjunct Prof. Kanna Rajan
Main publications: see list below ref [P3.R1]

Over the last decade, ocean sunfish movements have been monitored worldwide using various satellite tracking methods. This study reports the near-real-time monitoring of the fine-scale (< 10 m) behaviour of sunfish. The study was conducted in southern Portugal in May 2014 and involved satellite tags and underwater and surface robotic vehicles to measure both the movements and the contextual environment of the fish.

A total of four individuals were tracked using custom-made GPS satellite tags providing geolocation estimates of fine-scale resolution. These accurate positions further informed sunfish areas of restricted search (ARS), which were directly correlated to steep thermal frontal zones. Simultaneously, and for two different occasions, an Autonomous Underwater Vehicle (AUV) video-recorded the path of the tracked fish and detected buoyant particles in the water column. Importantly, the densities of these particles were also directly correlated to steep thermal gradients. Thus, both sunfish foraging behaviour (ARS) and possibly prey densities were found to be influenced by analogous environmental conditions. In addition, the dynamic structure of the water transited by the tracked individuals was described by a Lagrangian modelling

Figure 13: The picture shows the Telemetron USV immediately prior to launching the LAUV AUV in the Trondheimsfjord. The scenario was surveying for old wrecks, therein using the range and speed of the USV to quickly scan an area of interest. Thereafter, the AUV is sent down to perform a closer inspection. The USV acts as an aiding relay platform for the AUV in providing communication and global positioning updates to the AUV. Hence, significant cost savings can be achieved. Photo: Maritime Robotics AS.



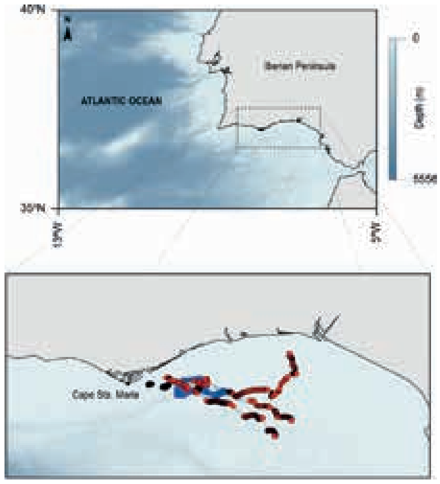


Figure 14 (left): The integrated monitoring concept is illustrated in the figure. ***Figure 15 (right):*** *The figure shows a map defining the study region, SW Iberian, including the northern margin of the Gulf of Cadiz and the Strait of Gibraltar. Bathymetric chart denoted by the blue bar. Detailed tracks recorded in this study are represented in the inset and all tracks recorded (AUV—black; WaveGlider—blue and sunfish GPS—red dots).*

approach. The model informed the distribution of zooplankton in the region, both horizontally and in the water column, and the resultant simulated densities positively correlated with the sunfish ARS behaviour estimator. The model also revealed that tracked fish opportunistically displace with respect to subsurface current flow. Thus, we show how physical forcing and current structure provide a rationale for a predator's fine-scale behaviour observed over a two-week period.

Autonomous tracking of surface targets from unmanned aerial vehicles
Key scientists: Profs. Thor I. Fossen and Tor Arne Johansen
PhD candidate: Frederik Leira

The PhD thesis by Frederik Leira, "Object Detection and Tracking with UAVs – A framework for UAV object detection and tracking using a thermal imaging camera", was submitted in November 2016. The thesis contains novel algorithms and validation using flight tests, including successful autonomous detection and tracking of ice floes near Svalbard. In this test, the UAV achieves on-board real-time processing of the video stream from a thermal camera and autonomously both detects the drifting ice floe and tracks its position and velocity.

COLREGS-compliant collision avoidance for autonomous surface vehicles
Key scientist: Prof. Tor Arne Johansen
Main publications: see list below ref [P3.R2]
The recent paper describes a concept for a collision avoidance system for ships based on model predictive control.

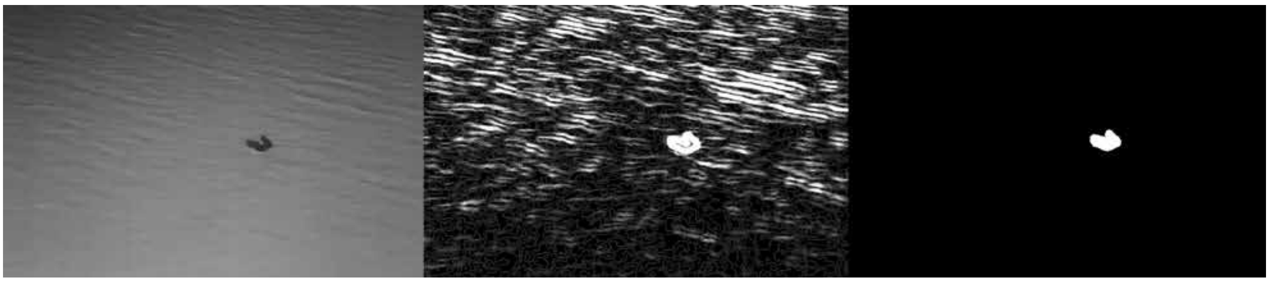


Figure 16: *The pictures show the following: left) raw thermal image, where the dark (cold) part is the ice floe; middle) same image with enhanced features by edge detection; right) segmented image, where only the features of interest (the ice floe) remain.*

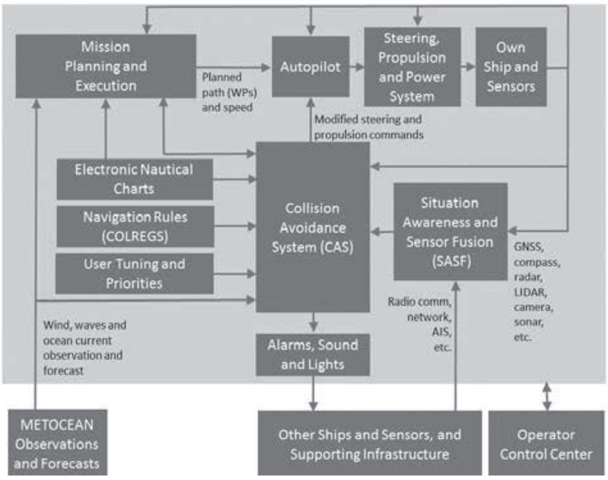


Figure 17: *The figure illustrates the system architecture, where the Collision Avoidance System (CAS) can be easily integrated with convention ship systems.*

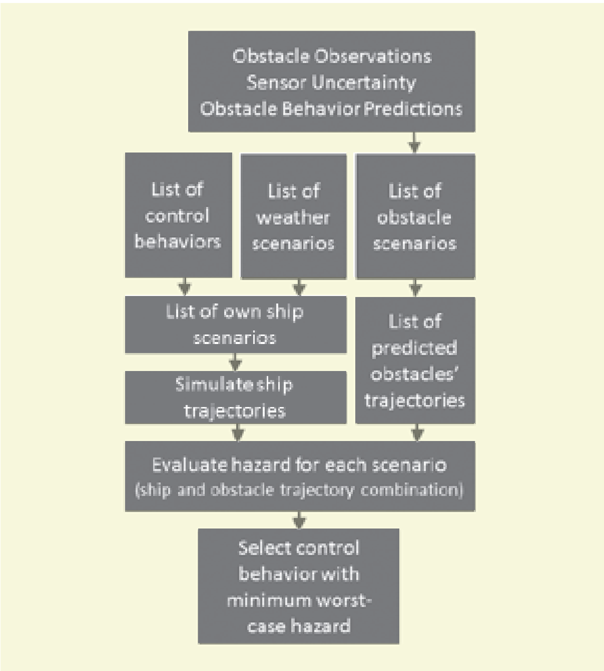


Figure 18: *The main concept is illustrated in the flow diagram. A finite set of alternative control behaviours is generated by varying two parameters: offsets to the guidance course angle commanded to the autopilot and changes to the propulsion command ranging from nominal speed to full reverse. Using simulated predictions of the trajectories of the obstacles and ship, the compliance with COLREGS and collision hazards associated with each of the alternative control behaviours are evaluated on a finite prediction horizon, and the optimal control behaviour is selected. Robustness to sensing error, predicted obstacle behaviour, and environmental conditions is ensured by evaluating multiple scenarios for each control behaviour.*

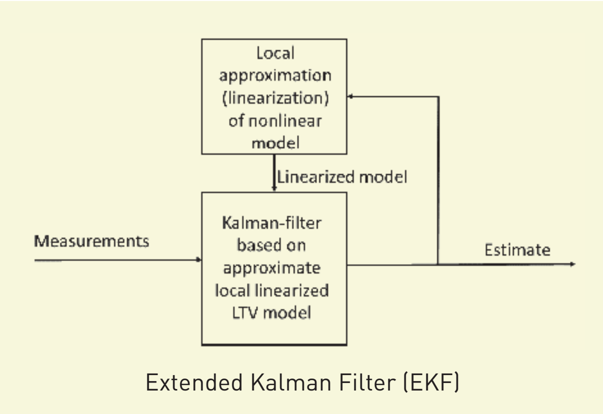
The method is conceptually and computationally simple yet quite versatile, as it can account for the dynamics of the ship, the dynamics of the steering and propulsion system, forces due to wind and ocean current, and any number of obstacles. Simulations show that the method is effective and can manage complex scenarios with multiple dynamic obstacles and uncertainty associated with sensors and predictions.

Global and accurate filtering for navigation

Key scientists: Profs. Tor Arne Johansen and Thor I. Fossen

It is well known that the classical time-varying Kalman Filter (KF) is globally exponentially stable and optimal in the sense of minimum variance under certain conditions. However, nonlinear approximations, such as the Extended KF (EKF), linearize the system about the estimated state trajectories, leading in general to loss of both global stability and optimality. Nonlinear observers tend to have strong, often global, stability properties. They are, however, often designed without optimality objectives considering the presence of unknown measurement errors and process disturbances.

In a recent paper [P3.R3], the cascade of a global nonlinear observer with the linearized KF, where the estimate from the nonlinear observer is an exogenous signal only used for generating a linearized model to the KF. It is shown that the two-stage nonlinear estimator inherits the global stability property of the nonlinear observer, and simulations indicate that local optimality properties similar to a perfectly linearized KF can be achieved. This two-stage estimator is called an eXogeneous KF (XKF), and when the first stage can also be realized as a KF via model transformations, it is referred to as a Double KF (DKF), [P3.R4]. Applications of the new estimation approach for navigation are given in references [P3.R5-7].



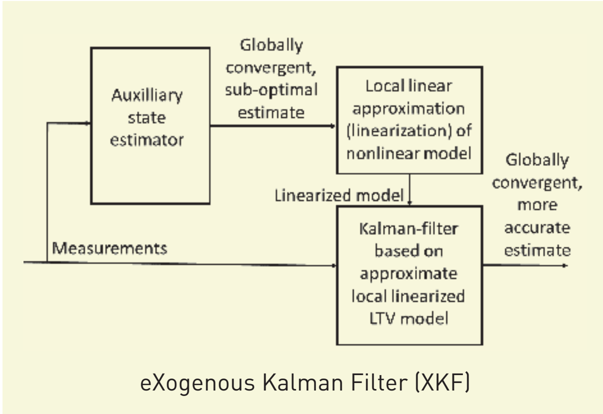


Figure 19: The difference between the well-known EKF and the new XKF is illustrated in the figure. The potentially destabilizing feedback loop of the EKF is replaced by a stable feed forward from a globally stable auxiliary state estimator.

Selected references

P3.R1. **Sousa, Lara L; López-Castejón, Francisco; Gilabert, Javier; Relvas, Paulo; Couto, Ana; Queiroz, Nuno; Caldas, Renato; Dias, Paulo Sousa; Dias, Hugo; Faria, Margarida; Ferreira, Filipe; Ferreira, António Sérgio; Fortuna, João; Gomes, Ricardo Joel; Loureiro, Bruno; Martins, Ricardo; Madureira, Luis; Neiva, Jorge; Oliveira, Marina; Pereira, João; Pinto, José; Py, Frederic; Queirós, Hugo; Silva, Daniel; Sujit, P. B.; Zolich, Artur Piotr; Johansen, Tor Arne; Sousa, João Borges de; Rajan, Kanna.** Integrated Monitoring of Mola mola Behaviour in Space and Time. PLoS ONE 2016. DOI http://dx.doi.org/10.1371/journal.pone.0160404

P3.R2. **Johansen, Tor Arne; Perez, Tristan; Cristofaro, Andrea.** Ship Collision Avoidance and COLREGS Compliance using Simulation-Based Control Behavior Selection with Predictive Hazard Assessment. IEEE transactions on intelligent transportation systems (Print) 2016 ;Volume 17. p. 3407-3422

P3.R3. **Johansen, Tor Arne; Fossen, Thor I.** The eXogenous Kalman Filter (XKF). Published online in 2016 in International Journal of Control. DOI http://dx.doi.org/10.1080/00207179.2016.1172390

P3.R4. **Johansen, Tor Arne; Fossen, Thor I**. Nonlinear Filtering with eXogenous Kalman Filter and Double Kalman Filter. European Control Conference; 2016-06-29 - 2016-07-01

P3.R5. **Stovner, Bård Bakken; Johansen, Tor Arne; Fossen, Thor I.; Schjølberg, Ingrid.** Three-stage filter for position and velocity estimation from long baseline measurements with unknown wave speed. American Control Conference (ACC) 2016 p. 4532-4538

P3.R6. **Johansen, Tor Arne; Fossen, Thor I.; Goodwin, Graham C.** Three-stage filter for position estimation using pseudorange measurements. IEEE Transactions on Aerospace and Electronic Systems 2016 ;Volume 52.(4) p. 1631-1643

P3.R7. **Johansen, Tor Arne; Fossen, Thor I.** Nonlinear Observer for Tightly Coupled Integration of Pseudorange and Inertial Measurements. IEEE Transactions on Control Systems Technology 2016 ;Volume 24.(6) p. 2199-2206

Autonomous underwater robotics for mapping, monitoring and intervention

Project manager: Prof. Kristin Y. Pettersen
Scientists at NTNU: Profs. Hefeng Dong, Odd M. Faltinsen, Thor I. Fossen, J. Tommy Gravdahl, Marilena Greco, Geir Johnsen, Martin Ludvigsen, Ingrid Schjølberg, Roger Skjetne, Asgeir J. Sørensen and Houxiang Zhang
Other involved scientists: Prof. Jørgen Berge (University of Tromsø/UNIS), Prof. Roy E. Hansen (University of Oslo), Kjetil Bergh Ånonsen (Norwegian Defence Research Establishment (FFI), Prof. Mogens Blanke and Assoc. Prof. David Johan Christensen (Technical University of Denmark), Prof. Thijs J. Maarleveld (University of Southern Denmark), Prof. Gianluca Antonelli (University of Cassino, Italy), Prof. Sauro Longhi (UNIVPM, Italy), Prof. Tim W. Nattkemper (Bielefeld University, Germany), Dr Francesco Scibilia and Dr Vidar Hepsø (Statoil), Dr Ståle Johnsen (SINTEF)
Postdocs: Dr Pål Liljebäck, Dr Eleni Kelasidi
PhD candidates: Dennis J.W. Belleter, Anna Kohl, Mikkel Cornelius Nielsen, Stein Melvær Nornes, Martin Syre Wiig, Øyvind Ødegaard, Walter Caharija, Mauro Candeloro, Daniel de Almeida Fernandes, Signe Moe, Ingunn Nilssen, Petter Norgren, Ehsan Rezapour, Filippo Sanfilippo, Jørgen Sverdrup-Thygeson, Inga Aamot
Website: www.ntnu.edu/amos/project-4

This project concerns fundamental research on methods for autonomous underwater operations and systems including one or several underwater robots, such as ROVs and AUVs, and other sensor platforms for mapping and monitoring. Additionally, autonomous surface vessels (ASVs) are considered. Furthermore, intervention operations with combined vehicle and manipulator control are studied. The project focuses on the automation of tasks and functions of ROVs, ASVs and AUVs that are necessary to achieve robust autonomous systems, using mathematical models, real-time data and advanced algorithms such as numerical optimisation and nonlinear control. In addition to considering existing sensor platforms, the project also investigates new, cutting-edge sensor platforms that are bio-motivated, therein using cross-disciplinary expertise in AMOS covering biology, hydrodynamics and cybernetics.

Associated projects

Control, information and communication systems for environmental and safety critical systems
Programme: RCN SUP 2009 - 2014
Project manager: Prof. Kristin Y. Pettersen
Scientists: Profs. Thor I. Fossen, Jan Tommy Gravdahl, Lars Imsland, Tor Arne Johansen, Anton Shiriaev, Asgeir J. Sørensen and Ole Morten Aamo
Involved PhD candidates and postdocs: 6 PhD candidates and 2 postdocs

The project goal was to develop advanced information and communication technology (ICT) for important applications, such as those in the marine and maritime industry and in the oil and gas industry, and for sustainable energy production. The project presented, amongst others, new research results for robot manipulators that are mounted on moving platforms. This included results for robot manipulators mounted on ships, unmanned underwater vehicles and satellites. Singularity-free models were developed for the combined motion of the robot manipulator and the platform, and algorithms based on optimisation were developed that utilised, instead of counteracted, the environmental forces, something which was shown to significantly reduce the energy consumption. Another research topic addressed by this project was communication within networks of mobile units. The project developed algorithms for path planning for these communication nodes, which satisfy the dynamic limitations and properties of planes and helicopters, airspace limitations and collision avoidance while the data rate between the different nodes is maintained as high as possible. The project was finalised in September 2014. The project had then published more than 200 papers in international journals, books and conferences.

Snake locomotion in challenging environments
Programme: RCN FRINATEK 2011 – 2015
Project manager: Prof. Kristin Y. Pettersen
Scientists: Prof. Jan Tommy Gravdahl, Ass. Prof. Øyvind Stavdahl, Aksel Transeth (SINTEF ICT)
Involved PhD candidates and postdocs: 2 PhD candidates and 1 postdoc

The Snake Robotics Laboratory, Department of Engineering Cybernetics, NTNU, was developed during this project.

The project goal was to develop new methods and tools for snake robot locomotion in challenging environments on land and underwater. Inspired by biological snakes, external objects and irregularities are considered beneficial to snake robots 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 aspect 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 achieved research results that create synergies between environment interaction and forward propulsion of snake robots. Furthermore, the project developed new research results for the control of snake robots moving both on ground and in water.

The underwater swimming manipulator – a bio-inspired AUV
Programme: VISTA 2015 – 2018
Project manager: Prof. Kristin Y. Pettersen
Involved PhD candidates: 1

The project is funded by the Norwegian Academy of Science and Letters and Statoil. The underwater swimming manipulator (USM) is a novel bio-inspired autonomous underwater vehicle (AUV) with the ability to perform inspection and light intervention tasks in narrow spaces in subsea infrastructure, areas which are difficult to reach with conventional underwater vehicles. A USR is a slender, articulated structure consisting of serially connected joint modules, equipped with thrusters along its body. The USM can swim like a biological eel; in addition, it possesses hovering capabilities. The project goal is to generate research results targeting the control and thruster allocation of the USM.

Resident robot manipulators for subsea IMR
Programme: VISTA 2016 – 2018
Project manager: Prof. Kristin Y. Pettersen
Involved postdocs: 1

Research activity: The project is funded by the Norwegian Academy of Science and Letters and Statoil. The project goal is to develop research results necessary for implementing the USM as a resident robotic solution for the inspection, maintenance and repair of subsea installations (subsea IMR). The project focuses on efficiency and manoeuvrability, energy autonomy and the automatic docking of swimming robot manipulators.

Main results

Underwater snake robots offer many interesting capabilities for underwater operations. The long and slender structure of such robots provides superior capabilities for access through narrow openings and within confined areas. This is highly relevant 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, bio-inspired 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 facing underwater robots. Moreover, energy efficiency is one of the main challenges to the long-term autonomy of these systems. In the project, both of these aspects of efficiency are considered. We have analysed and experimentally investigated the fundamental properties of the velocity and power consumption of underwater snake robots. In particular, we have investigated the relationship between the parameters of the most common motion gait patterns, which are lateral undulation and eel-like motion, and the forward velocity and energy consumption. The analysis shows direct relationships among the amplitude, frequency and phase shift of the gait pattern and the forward velocity and power consumption. Both simulations and experiments are performed to validate the analysis, and both simulation and experimental results are seen to support the theoretical findings [P4.R1, R3, R6].

Fault tolerance is essential for safe and reliable underwater operations, in which the working environment may not allow emergency resurfacing. These environments may encompass under-ice operations or structural inspection and intervention inside subsea installations. The fault-tolerant control of underwater robots has been an active area of research for two decades. As fault-tolerant control has matured, new frontiers have opened, including approaches that ensure fault-tolerant control for multi-agent systems. Within this project, we address the research challenges of fault-tolerance and reconfiguration for collaborating heterogeneous underwater robots using sensor reconfiguration for the graceful degradation of navigation, fault-tolerant thruster reconfiguration and distributed fault-tolerant diagnosis, as well as modular vehicle modelling. The goal is to obtain fault tolerance using heuristics from multiple heterogeneous AUVs.

New results concerning the fault diagnosis and robust navigation of underwater robots were presented in [P4.R9]. A particle filter (PF)-based robust navigation with fault diagnosis (FD) is designed for an underwater robot, in which ten failure modes of sensors and thrusters are considered. The nominal underwater robot and its anomaly are described by a switching-mode hidden Markov model. By extensively running a PF on the model, the FD and robust navigation are achieved. The closed-loop full-scale experimental results show that the proposed method is robust and can both effectively diagnose faults and provide reasonable state estimation in cases where multiple faults occur. The comparison with other methods indicates that the proposed method is easily implemented and can diagnose all faults within a single structure as well as simultaneous faults.

NTNU AMOS has conducted several missions and research campaigns for ocean and seabed mapping in Norwegian waters and the Arctic using heterogeneous technology platforms such as AUVs, ROVs, ASV, UAVs and ship-based systems. The methodology for the integrated environmental mapping and monitoring of the seabed and the oceans (Figure 23) as well as the autonomy aspect (Figure 22) are addressed in P4.R10, R11. Associated definitions and requirements related to autonomy are also addressed.

Selected references:

P4.R1. **Kelasidi, Eleni; Jesmani, Mansoureh; Pettersen, Kristin Ytterstad; Gravdahl, Jan Tommy.** Multi-objective optimization for efficient motion of underwater snake robots. Artificial Life and Robotics 2016 ;Volume 21.(4) p. 1-12

P4.R2. **Caharija, Walter; Pettersen, Kristin Ytterstad; Bibuli, Marco; Calado, Pável; Zereik, Enrica; Braga, Jose; Gravdahl, Jan Tommy; Sørensen, Asgeir Johan; Milovanovic, Milan; Bruzzone, Gabriele.** Integral Line-of-Sight Guidance and Control of Underactuated Marine Vehicles: Theory, Simulations and Experiments. IEEE Transactions on Control Systems Technology 2016 ;Volume 24.(5) p. 1623-1642

P4.R3. **Kelasidi, Eleni; Liljebäck, Pål; Pettersen, Kristin Ytterstad; Gravdahl, Jan Tommy.** Biologically Inspired Swimming Snake Robots: Modeling, Control and Experimental Investigation. IEEE Robotics and Automation Magazine 2016 ; Volume 23. p. 44-62.

P4.R4. **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

P4.R5. **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

P4.R6. **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)

P4.R7. **Pettersen, Kristin Ytterstad.** Underactuated Marine Control Systems. I: Encyclopedia of Systems and Control. Springer 2014 ISBN 978-1-4471-5102-9.

P4.R8. **From, Pål Johan; Gravdahl, Jan Tommy; Pettersen, Kristin Ytterstad.** Vehicle-Manipulator Systems. Springer 2014 (ISBN 978-1-4471-5462-4) 388 p. Advances in Industrial Control(1)

P4.R9. **Zhao, Bo; Skjetne, Roger; Blanke, Mogens; Dukan, Fredrik.** Particle Filter for Fault Diagnosis and Robust Navigation of Underwater Robot. IEEE Transactions on Control Systems Technology 2014 ;Volume 22.(6) p. 2399-2407

P4.R10. **Ludvigsen, Martin; Sørensen, Asgeir Johan.** Towards integrated autonomous underwater operations for ocean mapping and monitoring. Annual Reviews in Control 2016 ;Volume 42. p. 145-157

P4.R11. **Nilssen, Ingunn; Ødegård, Øyvind; Sørensen, Asgeir Johan; Johnsen, Geir; Moline, Mark A.; Berge, Jørgen.** Integrated environmental mapping and monitoring, a methodological approach to optimise knowledge gathering and sampling strategy. Marine Pollution Bulletin 2015 ;Volume 96.(1-2) p. 374-383

Prototype

To experimentally verify the theoretical results, the project developed a novel snake robot prototype with force/torque sensors for sensing obstacles in an environment. The robot can also swim underwater due to its watertight design. The robot is a swimming manipulator arm and is developed using cross-disciplinary research across biology, hydrodynamics and cybernetics.

Figure 20: *Mamba – a novel snake robot prototype with force/ torque sensors for sensing obstacles in the environment.*

Figure 21: *Mamba - an amphibious robot able to move both on ground and in water.*

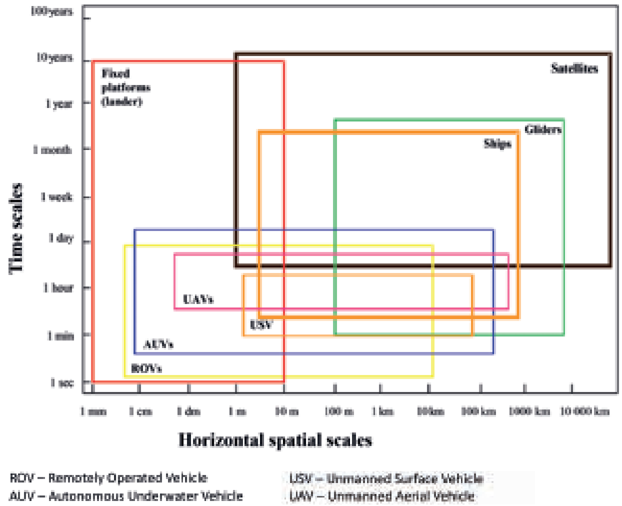


Figure 23: *Technology platform for spatial and temporal environmental mapping and monitoring (P4.R11).*

Industrial impact and cooperation

To bring the research from the laboratories and into industrial use, a NTNU AMOS spin-off company, Eelume, was established in June 2015. In April 2016, Eelume entered a partnership with Kongsberg Maritime and Statoil to accelerate the industrialization process and market entry. Eelume was awarded "Subsea Upcoming Company of the Year" by GCE Subsea in 2016.

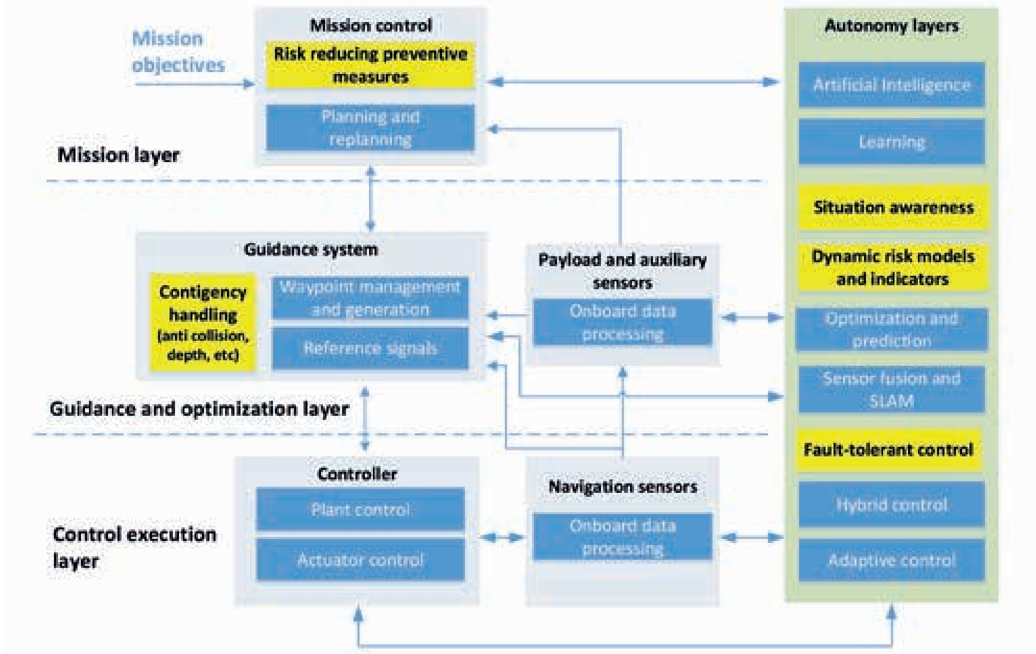


Figure 22: *Control architecture for autonomous technology platform (P4.R10).*

Figure 24: *Partnership between Eelume, Kongsberg Maritime and Statoil.*

Media coverage:

- Maritime Journal: The shape of things to come, November 2016
- Upstream Technology: See snake, no. 3, 2016
- GCE Subsea: Subsea upcoming company of the year, 15 June 2016
- NRK Dagsrevyen 21: Slangerobot på havbunnen, 18 April 2016
- E24: Denne slangeroboten skal bli Statoils "vaktmester" på havbunnen, 18 April 2016
- Teknisk Ukeblad: Slangeroboter skal revolusjonere vedlikeholdet subsea, 19 April 2016
- DYP Magasinet: Slangeroboter forbedrer subsea inspeksjon og vedlikehold, no. 2, 2016, p. 18-19

Plenary lectures at international conferences and distinguished lectures

- **Pettersen, Kristin Ytterstad**. Swimming snake robots – a bio-inspired solution for subsea inspection and intervention. IEEE International Symposium on Safety, Security, and Rescue Robotics (SSRR); 2016-10-23 - 2016-10-27
- **Pettersen, Kristin Ytterstad**. Snake robots for subsea inspection and intervention. Norwegian Maintenance Society´s Strategic Inspection Management Seminar; 2015-09-23 - 2015-09-24
- **Pettersen, Kristin Ytterstad**. Snake Robots – A solution for firefighting, search and rescue, and subsea IMR operations. The ECE Distinguished Lectures Series; 2015-10-22
- **Pettersen, Kristin Ytterstad**. Swimming manipulators – a bio-inspired underwater robotic solution. 10th IFAC Conference on Manoeuvring and Control of Marine Craft (MCMC); 2015-08-24 - 2015-08-26
- **Pettersen, Kristin Ytterstad; Liljebäck, Pål; Stavdahl, Øyvind; Gravdahl, Jan Tommy**. Snake Robots - From Biology to Nonlinear Control. IFAC Symposium on Nonlinear Control; 2013-09-04 - 2013-09-06
- **Sørensen, Asgeir Johan**. Marine Cybernetics: Enabling autonomous marine operations and systems. SOBENA Conference -The Brazilian Society of Naval Architecture, Marine and Offshore Engineering Conference (SOBENA); 2016-11-08 - 2016-11-10
- **Sørensen, Asgeir Johan; Ludvigsen, Martin**. Towards Integrated Autonomous Underwater Operations. IFAC Workshop on Navigation, Guidance, and Control of Underwater Vehicles; 2015-04-28 - 2015-04-30

Autonomous aerial systems for marine monitoring and data collection

Project manager: Prof. Thor I. Fossen
Scientists: Prof. Tor Arne Johansen, Dr Morten Breivik, Associate Prof. Edmund Brekke, Adjunct Associate Profs. Nadia Sokolova and Rune Storvold
PhD candidates: Kim Lynge Sørensen, Mariann Merz, Joao Fortuna, Kristoffer Gryte, Kasper Trolle Borup, Christopher Dahlin, Lorenzo Fusini, Jakob Mahler Hansen, Harald Lennart Jonatan Olofsson, Mikkel Eske Nørgaard Sørensen, Andreas Wolfgang Wenz
Website: www.ntnu.edu/amos/project-5

The main research challenges facing marine Unmanned Aerial Vehicle (UAV) operations concern requirements for fuel/weight, reliability and operational safety and are related to autonomy, communication, guidance and navigation. UAVs that carry sensors, communication equipment and other payloads can support operations such as ice management in the Arctic and the monitoring of resources, environmental parameters, such as oil spills, and traffic and operations at sea. To facilitate complex missions or tasks, UAVs will require autonomous mission planning capabilities to support simultaneous operations with multiple UAVs and other vessels. The research will focus on operations with UAVs that have the capability to handle a number of operational events without operator input, including intelligent command execution with path re-planning, energy management, fault-tolerant control, automatic launch and recovery from ships, operational safety and collision avoidance, management of communication quality of service, and online pursuit of mission objectives based on real-time payload sensor data information processing such as object tracking and obstacle avoidance, as well as optimal trajectory planning for updating estimates of distributed parameter phenomena being observed.

Associated projects

Low-cost integrated navigation systems using nonlinear observer theory (LowCostNav)
Programme: FRINATEK 2013-2016
Project manager: Prof. Thor I. Fossen
Involved PhD candidates: 3
Website: www.itk.ntnu.no/english/research/lowcostnav/Hovedside

The LowCostNav project was funded by the Norwegian Research Council through FRIPRO, and the outcomes were new nonlinear observers for attitude estimation and the integration of MEMS-based inertial sensors aided by position reference systems. Today, it is possible to buy accurate MEMS gyros and accelerometers with low-level software and built-in temperature compensation for less than USD 100. These units can be used in strapdown INS systems aided by GNSS, hydroacoustic positioning, radio or other position reference systems. The goal of the project was to replace the extended Kalman filter (EKF) with nonlinear observers for attitude determination and sensor integration without performance degradation. This has reduced the computational footprint significantly, and the new software can be used in various applications such as low-cost consumer electronics, cars, navigation systems for autonomous underwater vehicles (AUVs), ships, and unmanned aerial vehicles (UAVs).

Enhanced navigation algorithms in joint research and education
Programme: EEA Scholarship Programme and Bilateral Scholarship Programme (2016)
Project manager: Prof. Thor I. Fossen
Involved PhD candidates: 1

This project established a cooperation between NTNU and the Czech Technical University in Prague (CTU) and between NTNU AMOS and the Navigation Group of the Laboratory of Aircraft Instrumentation (NavLIS) at CTU. The project focused on merging the applied research of two research groups with a common aim to improve the performance of navigation systems. Accurate navigation systems are crucial in applications where the precise positioning of manned or unmanned vehicles is required.

Thus, "know-how" exchange enabled the comparison of utilised methodologies and approaches. The project exchanged best practices in the field of education and R&D. It also enhanced the level of the current state of the art in navigation systems and education practices, which are closely connected with R&D activities performed at both institutions.

Main results

Non-linear observers for robust GNSS- and camera-aided inertial navigation
Key scientists: Profs. Thor I. Fossen and Tor Arne Johansen
PhD candidates: Lorenzo Fusini, Håkon H. Helgesen

When operating UAVs in uncertain and harsh environments, robust navigation is crucial for the 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 a vehicle. The attitude of the vehicle is usually computed by sensing the gravitation vector, and this information is used together with magnetic field and GNSS speed/course-over-ground measurements. For autonomous vehicles, it is important to have redundant information if some of the sensors fail to recover the vehicle and avoid accidents. For this purpose, non-linear observers for sensor fusion have been developed. Such systems will be an important step towards the design of fully autonomous vehicles.

Camera-based navigation is crucial for achieving 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 enable the estimation of motion as either instantaneous image velocities or discrete image displacements.

A vision-aided non-linear observer and an eXogenous Kalman Filter (XKF) have been developed under the assumption of flat terrain (Fusini et al., 2017). The OF estimates the body-fixed relative velocity vector of the UAV, and this is used as an additional measurement of the non-linear 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. These data and measurements from other sensors are fed to the observer, and the origin of the estimation error is proven to be globally exponentially stable (GES).

The flat terrain assumption has been relaxed using epipolar coordinates or stereo vision (Hosen et al. 2016). When two cameras view a 3-D scene from two distinct positions, there are several geometric relations between the 3-D points and their projections onto the 2-D images, leading to constraints between the image points. These constraints are advantageous because 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 non-linear attitude observer. The equilibrium point of the estimation error is exponentially stable under the assumption that the gyro bias error is known.

Both observers have been implemented and tested experimentally on-board the Penguin fixed-wing UAV (see Figures 25–27). The performance of the observers is compatible with the extended Kalman filter (EKF) but with a smaller computational cost.

Selected publications:

- **Fusini, Lorenzo; Fossen, Thor I.; Johansen, Tor Arne.** Nonlinear Camera-Based INS for Fixed-Wing UAV using the eXogenous Kalman Filter. Chapter 1.2 in *Sensing and Control for Autonomous Vehicles:* Applications to Land, Water and Air Vehicles (eds. T. I. Fossen, K. Y. Pettersen and H. Nijmeijer). Springer, 2017.
- **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 ;Volume 39.(8) p. 1777-1789

Figure 25: The flight team at Eggemoen Aviation and Technology Park, Norway.

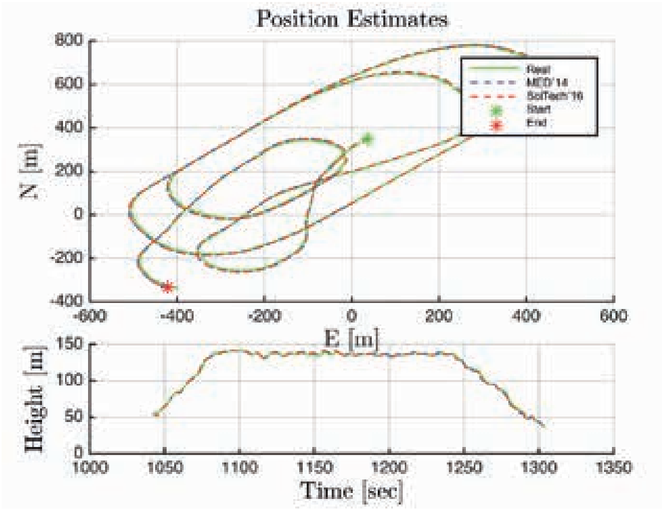


Figure 26: *North-East-Down position estimates for the two non-linear observers (flat terrain).*

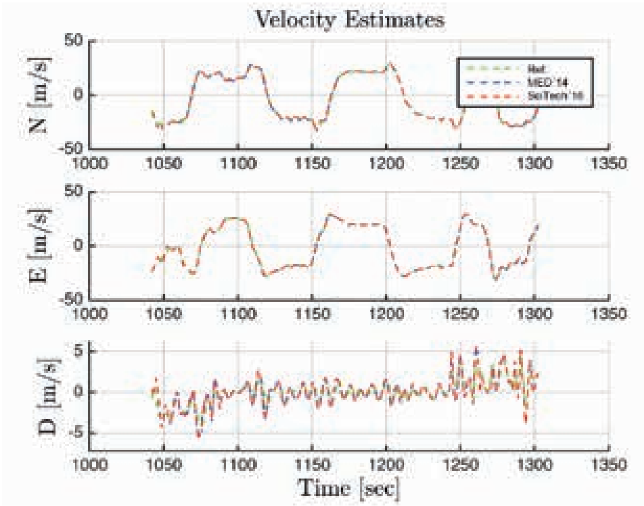


Figure 27: *North-East-Down velocity estimates for the two non-linear observers (flat terrain).*

Intelligent icing protection for small UAVs
Key scientist: Prof. Tor Arne Johansen
PhD candidate: Kim Lynge Sørensen

Icing is one of the most serious weather hazards in aviation. Present icing protection systems are typically heavy, expensive, structurally invasive, and/or environmentally harmful. However, most importantly, all present systems require human interaction. As such, these systems are not suitable for autonomous operation on-board unmanned aircraft.

Here at NTNU AMOS, we are developing an intelligent icing protection solution (IPS) for small UAVs. The objective of our research is to obtain a fully autonomous solution capable of icing detection, mitigation, and/or prevention depending on operational objectives and aircraft requirements. The solution is based on electro-thermal control of exposed aircraft surfaces, e.g., the leading edge of the aircraft wings and stabilisers. The system is based on three primary elements: electro-thermal sources, located on the exposed aircraft surfaces, with embedded temperature sensors; one or more power sources; and an intelligent central control unit. See Figure 28 for a schematic of the integrated solution.

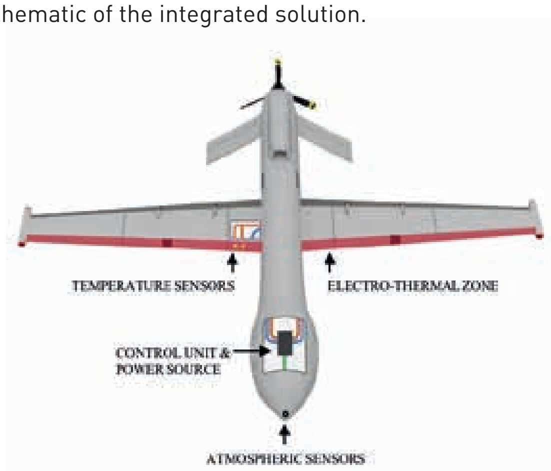


Figure 28: *Integrated layout of intelligent icing protection solution for unmanned aircraft.*

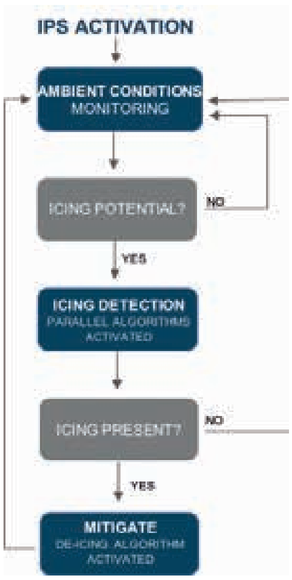


Figure 29: *A high-level representation of in-flight IPS operations.*

Two novel icing detection algorithms have been developed: one algorithm exploits changes in certain aerodynamic properties that occur when icing forms on exposed aircraft surfaces, and the other algorithm actively uses the electro-thermal sources to induce temperature changes, generating specific temperature profiles that vary with icing. Different control algorithms have been developed to accommodate both autonomous icing mitigation and autonomous icing prevention. Figure 29 is a high-level representation of in-flight autonomous icing mitigation.

Experiments were conducted under controlled conditions at the LeClerc Icing Research Laboratory, located in New York, in February 2016, and successful proof-of-concept test flights were conducted in April 2016 in Ny-Ålesund, Svalbard (see Figure 30). The first production phase embedded solution will be tested on the UAV labs' new Mini-Cruiser platform in April 2017, also in Ny-Ålesund. In June 2017, an upgraded software and hardware architecture will be integrated, therein incorporating CANaerospace protocols and a more modular design. This new prototype will be tested under controlled conditions at the Icing research tunnel at NASA Glenn Research Center. Throughout the fall of 2017, flight tests will be conducted in collaboration with NASA Ames Research Center and the University of Alaska Fairbanks in Oliktok, Alaska and Reykjavik, Iceland. The fall of 2017 will also see the first ever operational application of the intelligent icing protection solution, as the UAV lab in collaboration with Unis will conduct operations in Longyearbyen, with the objective of transmitting a live video feed of Auroras to the ground.

Figure 30: X8 Skywalker, fitted with the NTNU AMOS IPS, flying over Kongsfjorden, Ny-Ålesund, Svalbard.

Media coverage:
Inside unmanned systems (journal): New Technologies Aid Arctic Operations, 1 November 2015

Selected 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; Johansen, Tor Arne.** Thermodynamics of a carbon nano-materials based icing protection system for unmanned aerial vehicle. IEEE Aerospace Conference. Proceedings 2016 ;Volume 2016-June.

Autonomous recovery of a fixed-wing UAV on a ship using a net carried by multirotor UAVs
Key scientists: Profs. Thor I. Fossen and Tor Arne Johansen
PhD candidate: Kristian Klausen

Autonomous landing of UAVs on-board ships is a safety-critical operation, which requires a high degree of autonomy. Traditionally, a net located on the ship deck is used for recovering the fixed-wing UAV. However, there are numerous challenges when attempting autonomous landings in such environments. Waves will induce heave motion, and turbulence near the ship will make approaches challenging. Consequently, we have developed a new concept using multirotor UAVs to move the recovery operation off the ship deck (Klausen et al., 2016). To recover the fixed-wing UAV, a net is suspended below two coordinated multirotor UAVs which can synchronize the movement with the fixed-wing UAV. The approach trajectory can be optimized with respect to the wind direction and turbulence caused by the ship can be avoided. In addition, the multirotor UAVs can transport the net at a certain speed along the trajectory of the fixed-wing UAV, thus decreasing the relative velocity between the net and fixed-wing UAV to reduce the forces of impact.

To overcome the complexity of an autonomous recovery system for a fixed-wing UAV landing in a suspended net, the overall mission has been split into tasks:

- The fixed-wing UAV is instructed to follow a path against the wind, with the minimal airspeed required for safe flying. This is referred to as the "virtual runway". The UAV approach path is transmitted to the multirotor UAVs such that the position of the virtual runaway can be adjusted dynamically.

- Both multirotors are equipped with cooperative and coordinated control systems, which keep the formation of the two intact, while lifting the suspended net and maintaining its tension.
- The current position and the velocity of the fixed-wing UAV is transmitted to the autopilot in one of the multirotors, which sends desired set-points to the formation controllers to catch the fixed-wing UAV.

Although using two or more multirotor UAVs instead of one increases the complexity of the system, it has several practical advantages. First, by distributing the load, each multirotor can be physically smaller than a single one with the combined lift capacity. Furthermore, the two multirotors can spread the net without a support structure (top beam), giving reduced lifting weight.

Precise navigation is crucial for precision landing of UAVs. Hence, we utilize a Real-Time Kinematic (RTK) Global Navigation Satellite System (GNSS) in combination with range measurements. RTK GNSS is a navigation technique using the carrier wave of the incoming signals from the satellites to compare the signals to that received by a base station. By computing the phase shift between the signals at the UAV (rover) and the base, the location can be locked in at centimetre-level accuracy.

Several experiments have been performed at Agdenes airport. The net catching concept was successfully demonstrated in November 2016. The experiments verify the concept and theoretical results presented in Klausen et al. (2017). Future tests are planned on-board the NTNU research vessel Gunnerus.

Selected publication:

Klausen, Kristian;, Moe, J.B.; van den Hoorn, J.C.; Gomola, A.; Fossen; Thor I.; Johansen; Tor Arne. Recovery of a Fixed-Wing UAV on a Ship using a Net Carried by Multirotor UAVs. Proceedings of the International Conference on Unmanned Aircraft Systems (ICUAS); 2016-06-07 - 2016-06-10

Energy management and propulsion for greener operations of ships and offshore structures

Project manager: Prof. Tor Arne Johansen
Scientists: Profs. Marilena Greco, Asgeir J. Sørensen, Odd M. Faltinsen, Roger Skjetne, Marta Molinas and Ingrid B. Utne
PhD candidates: Shaojun Ma, Torstein I. Bø, Michel Miyazaki, Andreas R. Dahl, Espen Skjong, Børge Rokseth
Website: www.ntnu.edu/amos/project-6

Power and energy management on future vessels with hybrid electric power plants utilizing diesel, LNG, fuel cells, and novel power concepts, is studied. They must operate efficiently with respect to fuel and emissions within complex operational scenarios such as high waves and ice, and have built in autonomous fault-tolerant control execution strategies to manage faulty and abnormal conditions without blackout. The integrated hydrodynamic analysis and design of hull and propulsion characteristics is important on its own, and can provide optimal operating points for the operational strategy.

Outcomes are expected to be improved knowledge on the design of hull and propulsion for minimum resistance in ships, fault-tolerant power and propulsion control architectures and optimization-based control strategies that are able to autonomously handle the diversity of dynamic responses of hybrid energy sources, AC or DC electric distribution, and power consumers such as thrusters.

Associated research projects

Design and verification of control systems for safe and energy-efficient vessels with hybrid power plants (D2V)
Project manager: Prof. Asgeir J. Sørensen
Involved PhD candidates: 5

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 being used at an increasing rate, 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.

Optimization-based design of modular power management systems for modern ships, with focus on efficiency and fuel consumption
Project manager: Rune Volden (Ulstein Power & Control)
Supervisor: Prof. Tor A. Johansen
Funding: Research Council of Norway and Ulstein Power & Control AS
Involved PhD candidates: 1

With the stringent environmental regulations in the marine sector (e.g., IMO ECA zones), which limit the emission of greenhouse gases and particle matter near shores, smarter and more efficient shipboard power systems are needed. Such systems might utilize, for example, energy storage systems and apply optimal unit commitment (scheduling of power producers) to reduce the environmental footprint from burning fossil fuels. This calls for smarter integration of different power producers with the inclusion of optimal Power/Energy Management Systems (PMS/EMS) that utilize the power producers' optimal loading conditions in terms of fuel efficiency in power production.

This project is directed to develop a PMS/EMS in a modularized manner in which optimization techniques/tools are applied for the design to fulfil the requirements of certification bodies and to introduce more efficient operation of the components and overall system. The objective would be to integrate all the developed modules into a unified PMS/EMS that would harmoniously and hierarchically operate those modules according to the ship mission priorities:

- Prototype modules for a fuel-efficient and green power management system
- Higher power quality and reduced losses and reduced fuel consumptions and emissions

Main results

Development strategies for greener shipping
Scientist: Prof. Odd M. Faltinsen

According to various environmental impact assessments, ocean-going vessels, as the most important aspect of the maritime transportation industry, will have increasing influence on the global ecosystem in the near future. Reliable ship speed-loss estimation under real environmental conditions allows a more accurate prediction of the power increase and fuel consumption as well as gas emissions from ships. On the other hand, technological enhancements, such as improved hull designs as well as improvements in power and propulsion systems, could potentially reduce CO_2 emission by up to 35%. These measures could effectively be combined with several other operational measures, such as optimal weather routing and voyage planning for ships, to ensure that fuel consumption and CO_2 emissions from ships are minimized on every voyage.

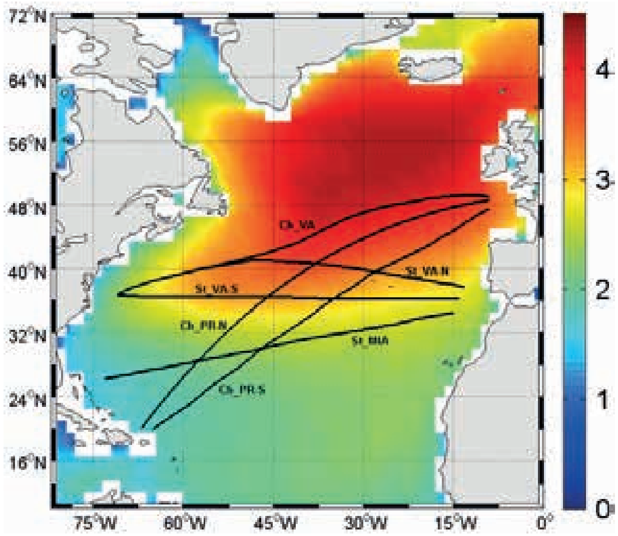


Figure 32: *Main North Atlantic trans-oceanic routes.*

A methodology for estimating the attainable ship speed, fuel consumption and CO_2 emissions in different sea states was developed [P6.R1]. The speed loss is calculated by considering the engine and propeller performance in actual seas as well as the inertia of the ship. The attainable ship speed is obtained as time series. The correlation of speed loss with sea states enables the prediction of propulsive performance in actual seas. If the computation is used for weather routing purposes, values for various ship initial speeds, loading conditions and heading angles for each realistic sea-state must be provided. The influence of various parameters, such as ship initial speed (full ahead and lower engine loads), loading condition, heading angle and weather conditions, on ship fuel consumption and CO_2 emissions was analysed. The voluntary speed loss was considered. The influence of

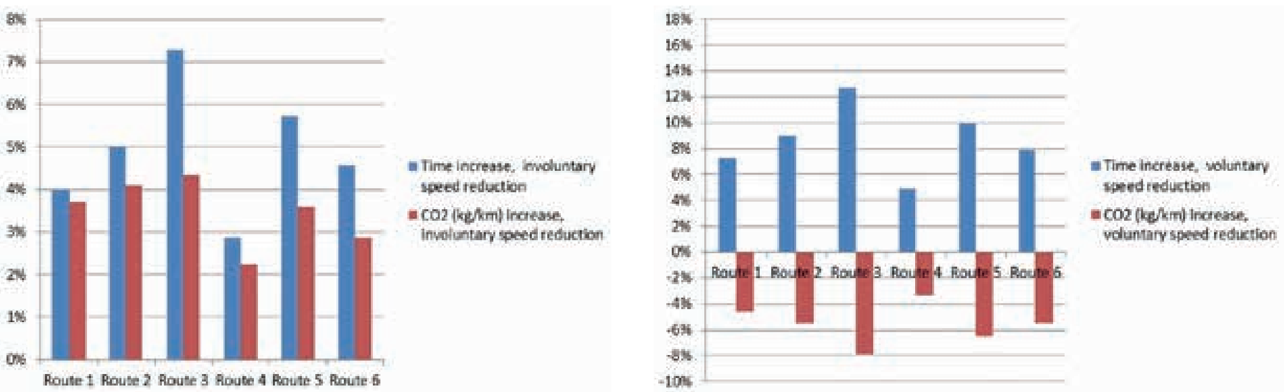


Figure 31: *Time increase and CO_2 emissions increase. Left: involuntary speed reduction. Right: voluntary speed reduction.*

the ship speed loss on various parameters, such as fuel consumption (time increase) and CO_2 emissions, was analysed for various routes of the Atlantic Ocean (Figure 32) using representative environmental design data for the track of the routes where the ship will sail. The results are reported in Figure 31 without and with effect of voluntary speed reductions. The latter plays an important role and can actually reduce emissions.

System-wide harmonic mitigation in a diesel-electric ship by model predictive control

Scientists: Profs. Marta Molinas and Tor A. Johansen
PhD candidate: Espen Skjong

To increase the overall efficiency of shipboard power systems, the over-dimensioning of safety constraints related to voltage drops and blackout prevention must be analysed, and the reactive power flow, which is related to harmonic pollution in the power system, must be minimized. Total Harmonic Distortions (THDs), which are measured as a normalized quantity of the harmonic pollution relative to the fundamental frequency components, are strictly regulated by classification societies and should in most cases be limited to less than 5%. Common practice for the control of Active Power Filters (APFs) for harmonic mitigation is to locally compensate the load current harmonics or to mitigate voltage harmonics at a single bus. As the operation of an APF in a multi-bus electrical system will influence the voltages of neighbouring buses, it is possible to optimize the APF operation from a system perspective instead of considering only conventional local filtering strategies. In this work (**[P6.R2]**), a system-oriented approach for mitigating harmonic distortions based on utilizing a single Active Power Filter (APF) in an electrical grid with multiple buses is proposed. The system-oriented harmonic mitigation method, which uses the framework of Model Predictive Control (MPC), utilizes a simplified model of the electrical system in the optimization strategy to generate APF current references that will minimize the harmonic distortions of the overall system within a given APF rating.

A diesel-electric ship, with two buses supplying separate harmonic loads, with an APF located at one of the buses, is used as a study case (Figure 32). The operation with on-line MPC-based optimization of the APF current references is compared with two benchmark methods based on conventional approaches for APF control: BM1, which uses the measured harmonic pollution from load 2 as the APF reference, and BM2, which uses the sum of the measured harmonic pollution at both buses as the APF reference. The results (Figure 31 and Table 1) demonstrate that the MPC generates current references that better utilize the APF current capability for system-wide harmonic mitigation. Because of the improved harmonic mitigation, the efficiency and reliability of the electrical system are increased.

	MPC	BM1	BM2
Voltage THD, load 1	2.8%	5.3%	3.1%
Voltage THD, load 2	2.8%	4.5%	3.4%
Load 1 element	12-pulse		
Load 2 element	6-pulse		
Power load 1	0.8 [pu]		
Power load 2	0.3 [pu]		

Table 1: Simulation results and power system configuration.

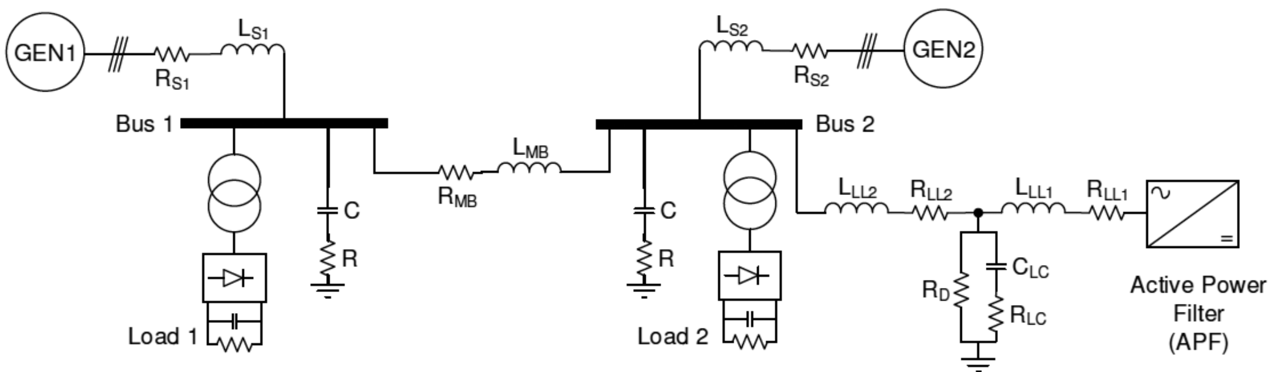


Figure 33: Single-line diagram of the shipboard electrical system used in simulations for the verification and comparison of different harmonic mitigation strategies.

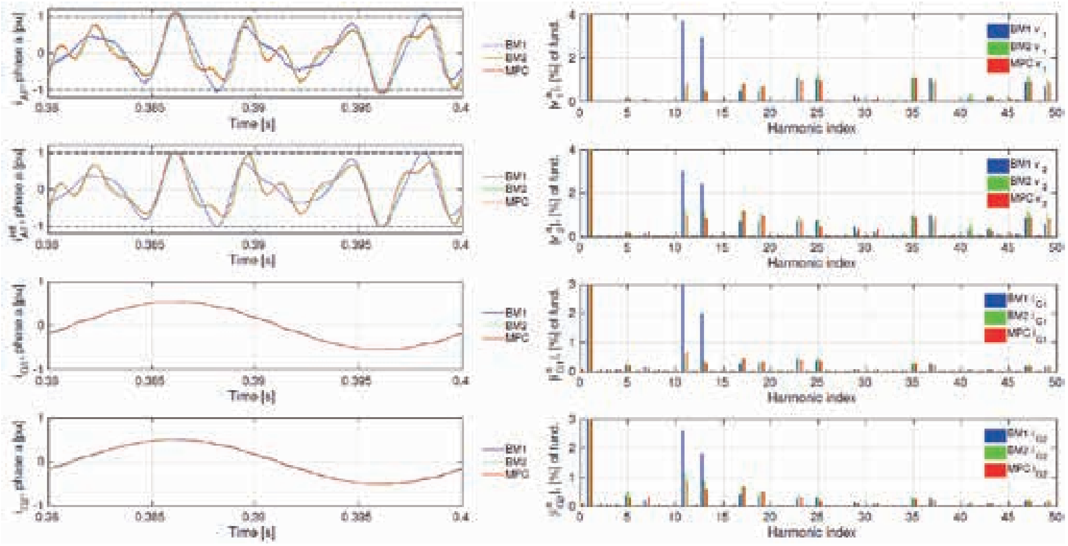


Figure 34: *Simulation results of harmonic mitigation in a two-bus shipboard electrical system. Right plot from above: APF current output from APF, APF reference, bus 1 generator current and bus 2 generator current. Left plot from above: Frequency spectra of bus 1 voltage, bus 2 voltage, bus 1 generator current, and bus 2 generator current.*

Scenario- and optimization-based control of marine electric power systems
Key scientists: Profs. Tor A. Johansen and Asgeir J. Sørensen
Postdoc: Dr Torstein Bø

A simulator of a marine vessel with a DP system was established and described in a recent article [P6.R3]. This systems-of-systems simulator includes the power plant, a hydrodynamic model, and control systems. The power plant includes generator sets, batteries, switchboards, thrusters, and hotel loads. Environmental loads, such as first- and second-order wave loads, mean and gusting wind, and ocean current, are included in the hydrodynamic model along with the hydrodynamic model of the vessel and the thrusters. The included control systems are a power management system, a DP-controller, thrust allocation, and low-level controllers of producers and consumers. Earlier marine vessel simulators mainly focused on the hydrodynamic model or the power plant. However, the present model combines the three models to investigate the complex integration and interaction effects between the models. These interaction effects are especially important when investigating the DP performance after faults in the power plant.

A simulation-based dynamic consequence analysis was further developed in [P6.R4]. The tool uses a simulator to simulate several possible worst-case scenarios. The operator can use this tool to optimize the electric power plant configuration and to show that no single failure leads to a loss of position. The dynamic consequence analysis is necessary when stand-by generators are considered, as the vessel may lose position during the time from when the fault occurs until the plant fully recovers, even if the vessel maintains its position after recovery.

Peak-shaving by batteries is used to cancel out power fluctuations, which cause variations in the electric grid's frequency. However, the batteries may become too hot if the power demand is excessive. The controller proposed in [P6.R5], based on a power spectrum analysis and MPC, reduces the power fluctuations as much as possible without letting the battery become too hot. Simulations using data generated by the simulator showed that the controller can achieve these objectives if the characteristics of the load do not change too rapidly.

Selected references

P6.R1. Prpic-Orsic, Jasna; Vettor, Roberto; Faltinsen, Odd Magnus; Guedes Soares, Carlos. The influence of route choice and operating conditions on fuel consumption and CO_2 emission of ships. Journal of Marine Science and Technology 2016 ;Volume 21.(3) p. 434-457

P6.R2. Skjong, Espen; Suul, Jon Are Wold; Rygg, Atle; Johansen, Tor Arne; Molinas Cabrera, Maria Marta. System-Wide Harmonic Mitigation in a Diesel Electric

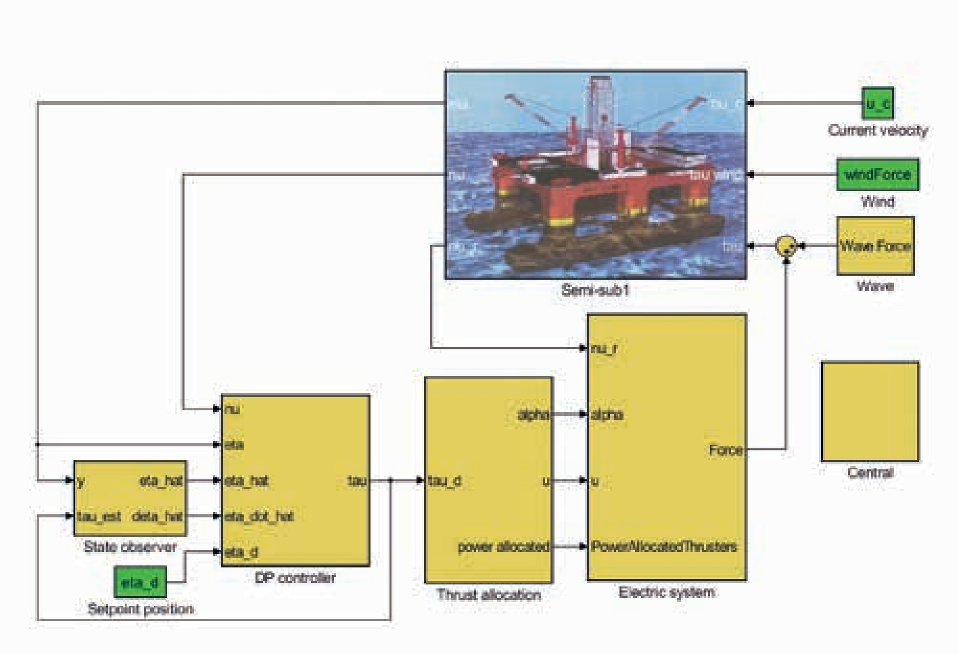


Figure 35: The marine system simulator with the new electric power system module is implemented in Matlab/Simulink and can be configured for a range of ships and vessels with different types of electric power plants.

Ship by Model Predictive Control. IEEE transactions on industrial electronics (1982. Print) 2016 ;Volume 63.(7) p. 4008-4019

P6.R3. **Bø, Torstein Ingebrigtsen; Dahl, Andreas Reason; Johansen, Tor Arne; Mathiesen, Eirik; Rejani Miyazaki, Michel; Pedersen, Eilif; Skjetne, Roger; Sørensen, Asgeir Johan; Thorat, Laxminarayan; Yum, Koosup.** Marine Vessel and Power Plant System Simulator. IEEE Access 2015 ;Volume 3. p. 2065-2079

P6.R4. **Bø, Torstein Ingebrigtsen; Johansen, Tor Arne; Sørensen, Asgeir Johan; Mathiesen, Eirik.** Dynamic consequence analysis of marine electric power plant in dynamic positioning. Applied Ocean Research 2016 ;Volume 57. p. 30-39

P6.R5. **Bø, Torstein Ingebrigtsen; Johansen, Tor Arne.** Battery power smoothing control in a marine electric power plant using nonlinear model predictive control. IEEE Transactions on Control Systems Technology 2016 ;Volume PP.(99)

Autonomous marine operations in extreme seas, violent water-structure interactions, deep waters and Arctic

Project manager: Prof. Asgeir J. Sørensen
Scientists: Profs. Jørgen Amdahl, Marilena Greco, Tor Arne Johansen, Thor I. Fossen, Roger Skjetne, Torgeir Moan, Odd M. Faltinsen, Trygve Kristiansen, Ingrid B. Utne and Oleksandr Tymokha; Adjunct Profs. Ulrik Dam Nielsen, Claudio Lugni and Vahid Hassani; Dr Morten Breivik, Dr Giuseppina Colicchio and Dr Jingbo Wang
PhD candidates: Astrid H. Brodtkorb, Finn-Christian W. Hanssen, Hans-Martin Heyn, Thomas Sauder, Svenn Are Tutturen Værnø, Stefan A. Vilsen, Dr Arnt Gunvald Fredriksen, Dr Øivind Kåre Kjerstad, Dr Bo Zhao, Ulrik Jørgensen, Zhengru Ren, Torleiv H. Bryne, Robert Rogne, Martin Hassel, Leif Erik Andersson, Einar S. Ueland
Website: www.ntnu.edu/amos/project-7

Vessels experiencing extreme sea conditions and violent water-structure interactions are examined. Fault-tolerant and safe control systems for marine craft and offshore structures operating in deep waters, extreme seas and Arctic areas are developed. In particular, hybrid control for dynamic positioning (DP) and kinematic estimation methods for the fast state estimation of marine vessels are studied and verified numerically as well as with full-scale experiments. The concept of hardware-in-the-loop (HIL) simulation is further developed for marine systems. The idea is to use real-time simulations to enlarge the applicability limits of marine-scale model basin laboratories. For example, the force of a deep-water riser on a DP scale model ship or floater can be physically transformed by a controlled actuator with force sensors (a robot arm) to a scale model using a real-time simulator of the riser dynamics. The key research outcomes are lab-in-the-loop prototype proof-of-concept for such applications in NTNU AMOS laboratories, including validation of the design using full-scale data and numerical simulations. Calculations of motion and load effects for slender structures and the assessment of fatigue, wear and ultimate strength of composite materials are all important for ensuring safe operation. This includes the characterization of the wave-current-wind environment in extreme weather conditions and the reliability assessment of existing sea models as well as their improvement. Short-term outcomes are non-linear hydrodynamic models, methods for motion and load effect calculation, and model-based control systems for the integrated use of inertial motion units (IMUs) in DP operations for improving autonomy and fault tolerance. The long-term outcomes are the demonstration of fully autonomous marine operations and new methods for the assessment of existing design and safety rules for vessels in extreme seas.

Associated projects and programmes

Fault-tolerant inertial sensor fusion for marine vessels (MarineINS)
Programme: MAROFF 2013-2016
Project manager: Prof. Thor I. Fossen
Involved PhD candidates: 2
Website: www.itk.ntnu.no/english/research/maroff13

The Fault-Tolerant Inertial Sensor Fusion for Marine Vessels (Marine INS) project is funded by the Research Council of Norway and Rolls-Royce Marine via MAROFF. The project has developed a new architecture and strap-down inertial navigation algorithms for ships, with a focus on dynamically positioned (DP) vessels, by using a nonlinear observer theory. In doing so, the project has utilized low-cost micro-electro-mechanical-system (MEMS)-based inertial measurement units (IMUs), in combination with various position reference systems, in order to provide motion and position estimates that have better accuracy and reliability. The software algorithms are employed based on a triple-redundant inertial sensor system, which is applicable to detect and identify sensor faults and failure situations.

Real-time hybrid model testing for extreme marine environments
Programme: MAROFF (1 April 2016 – 31 March 2020)
NTNU AMOS project manager: Prof. Roger Skjetne
Involved PhD candidates and postdocs: 1 PhD candidate and 1 postdoc

The project aims to develop Real-Time Hybrid Model Testing (or "hybrid testing") for extreme marine environments. Hybrid testing is a testing method in which the physical system under study is partitioned into two (or more) subsystems: a physical subsystem tested experimentally at model scale, connected in real time with a numerical subsystem, simulated on a computer. The two parts interact with each other using a suite of sensors, a communication network, actuators, and a control system for the actuation of the numerically calculated efforts in the «hybrid test loop».

Main results

A cost-effective redundant inertial navigation system (INS) for marine vessels
A redundant inertial sensor payload was installed on board an offshore vessel in the fall of 2015 in order to validate the software algorithms. The data acquisition system for the logging of the inertial sensor measurements during the ship operations contained four ADIS16485 IMUs from Analogue Devices and one STIM300 (high-end MEMS IMU) from Sensonor. In addition, the ship's motion data, including the roll, pitch, yaw, heave and horizontal position determined by the vertical reference units (VRU), compasses and GNSS position references, were collected for benchmarking, validation and comparison. In 2016, the data had been utilized to validate a triple-redundant INS based on 3x ADIS16485 IMUs. This was compared to an INS based on the STIM300 and demonstrated a favourable performance. The redundant INS was able to detect faulty inertial sensor readings with both established and new fault detection and identification (FDI) algorithms. Furthermore, the INS has an embedded VRU solution, providing the roll, pitch and heave, making additional sensor systems superfluous. This part of the INS has been further refined and now can provide a similar performance as the industry standard VRUs. Most notably, the heave estimation has been improved. The roll and pitch estimation performance have been verified by comparing the results obtained with the nonlinear observer to the performance with the navigation suite NavLab, which have been developed by the Norwegian Defence Research Establishment (FFI). In addition, the quality of the other sensors, such as GNSS, may change in time. Inherently, the sensor quality changes should be handled when utilized to aid the INS. The time-varying gains allow for an online retuning of the INS in the event of changes in the sensor quality and when disabling and re-enabling sensors. This is enabled by the developed sensor fusion algorithms based on nonlinear observers. The developed sensor fusion algorithms, based on low-cost MEMS sensors, are also able to operate with the dual redundant aiding from the positon and heading references, while

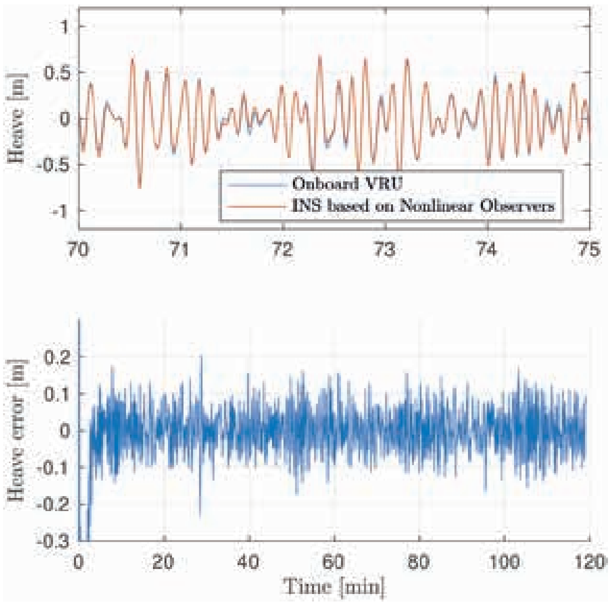


Figure 36: *The comparison of the heave estimation performance achieved with the nonlinear observers compared to the on-board VRU.*

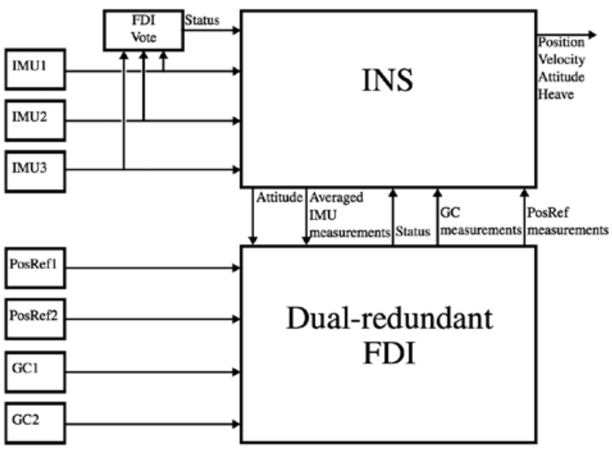


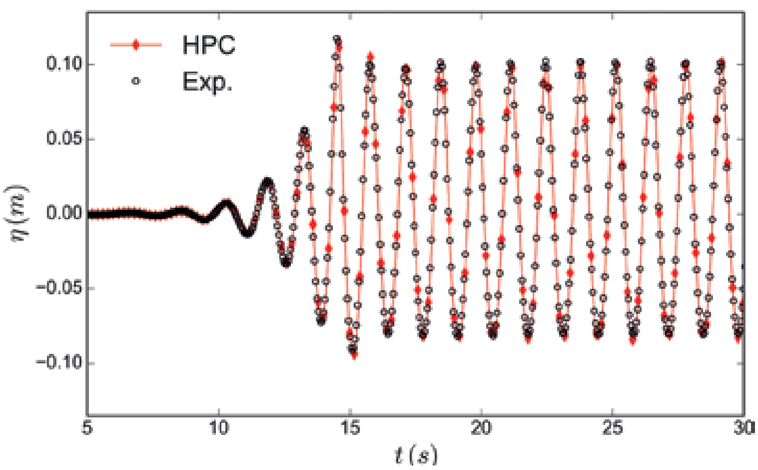
Figure 37: *The proposed sensor fusion architecture for the triple-redundant IMUs and the dual-redundant position references (PosRef) and gyrocompasses (GC).*

still providing accurate and robust ship motion estimates during DP without jeopardizing safety. This is enabled by the applied fusion architecture, which allows for both the FDI and high-performance position, velocity and attitude estimation by treating these two objectives separately. The applied fusion architecture still utilizes all the available information of the ship's motions, in both the FDI and performance aspects of the system, which are extracted from the sensor measurements and the INS's estimates.

Hydrodynamic highlights

An important part of the NTNU AMOS hydrodynamic research was dedicated to the development of several **Domain-Decomposition (DD)** strategies coupling different solvers to obtain an accurate and efficient solution of fluid-body interactions. Here, an example is briefly described. A 3D DD strategy has been proposed to address violent wave-ship interactions. The strategy couples a linear potential flow seakeeping solver with a Finite-Difference Navier–Stokes (FD-NS) method. The latter is applied in an inner domain where slamming, water-on-deck, and free surface fragmentation may occur. The DD is compared against experiments (at CNR-INSEAN) on a freely floating patrol ship in head sea regular waves [P7.R1]. The study highlighted the need for special care in ensuring a reliable solution in the region of the body shared by the two different solvers.

The development of innovative hydrodynamic solvers also represents a crucial target for NTNU AMOS. The **Harmonic Polynomial Cell (HPC) method** was proposed [P7.R2] as a new method for the Laplace equation, i.e., for potential-flow problems, able to achieve high accuracy and efficiency. A comparison against traditional panel methods showed that the HPC is i) able to solve large-scale problems and is ii) more accurate than and as stable as the low-order panel methods as well as more stable than high-order panel methods. This means that the HPC method can solve both linear and nonlinear problems in an efficient, accurate and stable manner. The original HPC was further extended to the solution of the Poisson equation [P7.R3], relevant for viscous flow problems, as well as improved in terms of formulation. An in-depth analysis of the HPC method's local and global properties was conducted in 2D to provide guidance for a rational implementation of the method. Strategies for cell selection and boundary treatment have been suggested to minimize error, including concepts such as the immersed boundary method and overlapping grids. The latter are especially useful when considering complex geometries or deforming boundaries such as a free surface. These concepts can be deployed when solving nonlinear wave-body interaction problems by treating the free surface as an immersed boundary in a structured background grid and using body-fixed overlapping grids on moving objects such as a wavemakers or a floating body. The 2D potential-flow HPC method is able to simulate steep waves (left of Figure 38) even up to the limit of breaking with good accuracy. It is also able to accurately predict the flow features and local induced pressures during water entry of solid objects (right of Figure 38).



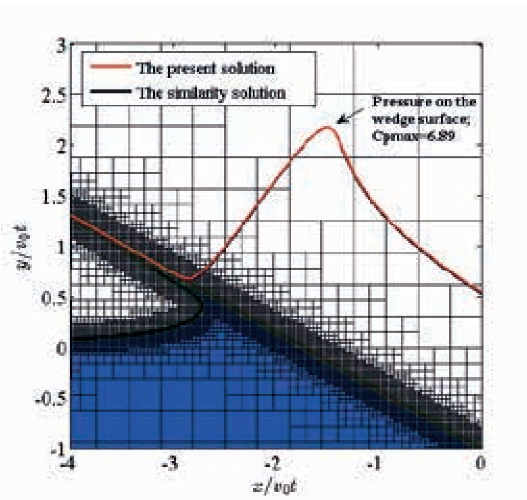


Figure 38: Examples of HPC applications. Left: evolution of wave elevation from HPC solver and experiments (Lugni 1999). Right: water entry of a wedge with a deadrise angle of 30° from HPC and similarity solution. v_0 is the entry wedge speed. The curves are solutions of the pressure coefficient Cp on the wetted wedge surface.

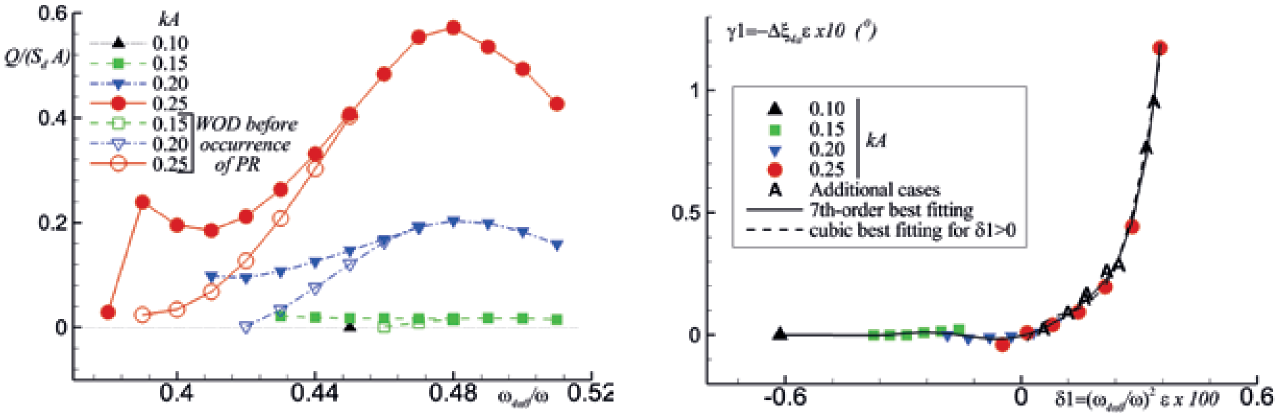


Figure 39: *Left: maximum shipped-water volume Q for an FPSO in steady-state conditions before and after PR. S_d=deck area, $\omega 4_{n0}/\omega$=calm-water roll natural frequency-to-incident wave frequency ratio and kA=incident-wave steepness. Right: scaling law for the variation in the roll amplitude $\Delta\xi_4$ caused by WOD loads.*

Water on deck (WOD) and **Parametric Resonance (PR)** can be induced on ships through interaction with steep waves. Their occurrence and mutual influence has been studied experimentally (at CNR-INSEAN) and numerically on a FPSO without mooring lines and bilge keels in head-sea regular waves [P7.R4]. A numerical DD strategy was proposed, therein coupling a weakly nonlinear potential-flow seakeeping solver with a shallow-water approximation of the WOD. The analysis shows that interaction with steeper waves brings the PR instability towards shorter waves. The phenomenon typically requires a long time to build up, and the steady-state roll amplitude exceeds 20° in the worst examined cases. PR makes water shipping asymmetric; it increases its severity (left of Figure 39) and can even be the cause of WOD. The latter affects PR and in general tends to increase the roll amplitude (right of Figure 39). From this study, the modified steepness ε= *(2A-f)*/λ (with A and λ being the incident amplitude and wavelength, respectively, and *f* being the ship freeboard) is an important parameter.

The DD was used to examine the platform with bilge keels both without and with the mooring-line system [P7.R5]. It was found that, with bilge keels with a length equal to 40% of the ship length and a breadth equal to 3% of the ship breadth limit effectively, the roll instability is promoted by vertical bow motions in waves. In addition, in these conditions, the amount of shipped water is substantially reduced. Large roll induced by coupling with lateral motions seems to be less well counteracted. Increasing the bilge-keel breadth is beneficial; however, a combination of the mooring system with dynamic positioning appears needed to ensure proper control of the roll motion in the worst examined cases.

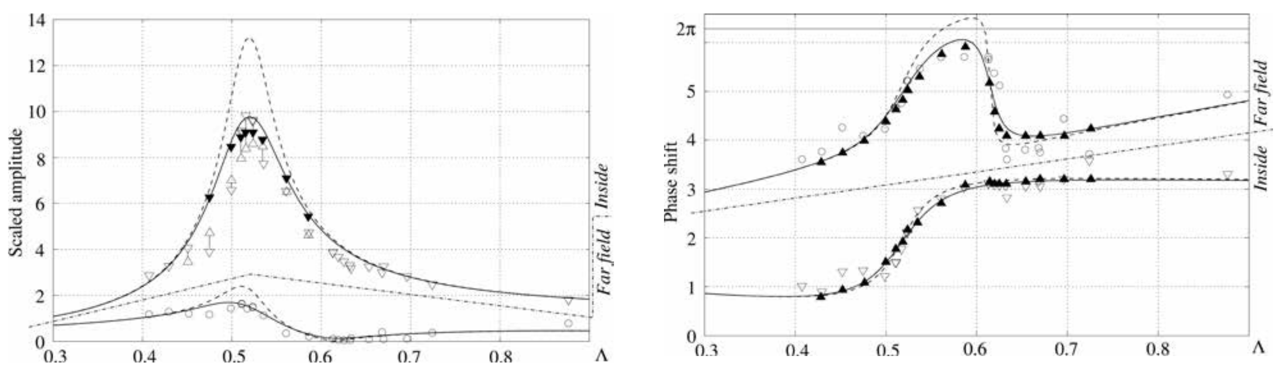


Figure 40: *Experimental (empty symbols, Faltinsen et al. 2007), numerical by a viscous solver (solid symbols), numerical by an inviscid solver (dashed lines) and present results for dimensionless wave amplitudes and phase shifts (inside the moonpool and in the far field) versus a frequency parameter Λ for a 2D moonpool in forced harmonic heave.*

Moonpools are openings in the bottom of ship hulls and are often used in marine operations to lower or lift devices such as subsea modules and ROVs. An important issue is the occurrence of **piston-mode resonance** for the water column inside the moonpool, which is characterized by up-and-down fluid motion. How large the water motion is 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. An old approach involves an inviscid hydrodynamic model using nonlinear damping terms with empirical coefficients. Various attempts to theoretically estimate these coefficients were unsuccessful. An analytical strategy has been proposed using a similarity between flows through moonpools and screens [P7.R6], therein obtaining reliable results (Figure 40).

A more general approach, based on a DD strategy, has also been proposed to directly model viscous effects where needed and preserve efficiency. The DD couples a potential-flow HPC method with a NS Finite-Volume method [P7.R7]. Experiments and numerical investigations suggested the possible use of moonpools to minimize the heave motion.

When the typical temporal duration of the local load is comparable with a natural period of the structural mode contributing to large structural stresses, **hydroelasticity** is significant and affects the integrity of the structure. The assessment of the structural strength of an **LNG membrane tank** exposed to dynamic and impulsive sloshing loads requires the prediction of the hydroelastic response of the structure. A detailed experimental investigation on the kinematical and dynamical flow field in a 2D sloshing tank in shallow water conditions has been performed. The strain distribution along a vertical deformable aluminium plate clamped in a fully rigid vertical wall has been measured. Froude scaling the lowest structural natural wet frequency of a prototype panel typically used in a Mark III containment system enables one to fix the sizes, thickness and structural properties of the deformable wall. The study [P7.R8] emphasizes the evolution of the hydroelastic phenomenon during a flip-through slamming event, characterized by three different regimes: quasi-static deformation of the beam (regime I), followed by a strong and fully coupled hydroelastic interaction (regime II) and finally by a free-vibration stage (regime III).

A hybrid numerical-experimental model has been proposed to model the structural load. The model couples the Euler beam theory with the experimental pressure measured in the rigid case. The added mass term comes from a potential flow model and assuming a quasi-static variation in the free surface. The instantaneous wetted length of the beam is determined by the experimental

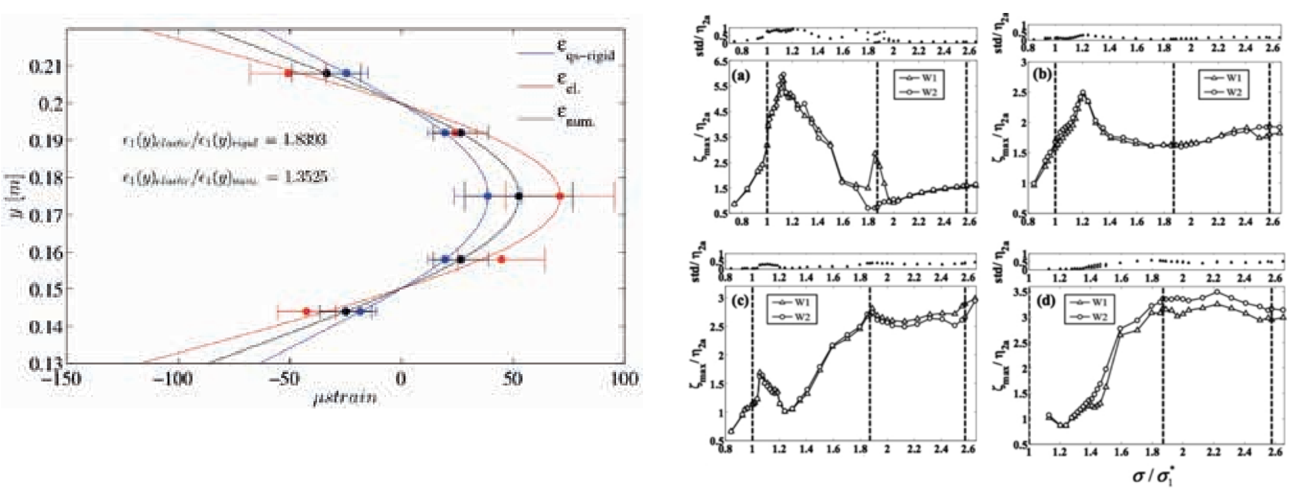


Figure 41: Left: comparison between numerical predictions of the present hybrid model (black symbol), those of a quasi-static model (ii) (blue symbol), and experimental results (red symbol) relative to the mean value (with error bars) of the maximum strain distribution along the elastic wall. Right: experimental maximum steady-state wave elevations at W1 and W2 (50 mm from two opposite vertical walls), scaled with the forcing amplitude, versus the non-dimensional forcing frequency ratio σ/σ_1. The ζ_{max} values are average values from repeated tests. The corresponding stds are shown in the top panels. The dark dashed vertical lines represent $\sigma_1/\sigma_1 = 1.00$, $\sigma_2/\sigma_1 = 1.87$, and $\sigma_3/\sigma_1 = 2.573$. (a) Sn = 0.000, clean tank; (b) Sn = 0.4752; (c) Sn = 0.676; (d) Sn = 0.796. σ_1 is the lowest natural frequency of the tank.

images. More simplified quasi-static theoretical models, typically used at the design stage, have also been implemented and compared with the hybrid model and the experimental data. This shows a relevant role of the added mass for the proper prediction of the dynamic maximum load as well as the role of the strain (or stress) as a reliable indicator of the maximum local load (left of Figure 41).

One method to **suppress liquid oscillations in a tank** is the use of a swash bulkhead in the centre of the tank, which is perpendicular to the main flow direction. A rectangular tank with low filling depth and centralized slat screens with different solidity ratios have been used to perform a detailed experimental investigation [P7.R9]. Among the four considered solidity ratios, Sn = 0.676 is able to successfully suppress slamming at the lowest natural frequency for the clean tank and exhibits the smallest maximum free-surface elevation (right of Figure 41), slamming pressure, and pressure impulse. This suggests that an optimal solidity ratio is approximately 0.6-0.7 for the applied filling level. This optimal solidity ratio has potential applications in areas such as swash bulkhead design and liquefied-cargo tank design in ship and offshore engineering.

Dynamic positioning of marine vessels in transient and stationary dynamics

Dynamic positioning (DP) systems are used on marine vessels for automatic station keeping and tracking operations solely through the use of thrusters. Observers estimate the position, velocity and heading for the DP controller, and two main observer types have been examined: the model-based type, used in steady-state conditions since it is especially good at filtering out first-order wave-induced motions and predicting states in the case of signal loss, and the signal-based type, which typically obtains superior performance during transients. A hybrid observer combining these two strategies with a performance monitoring function is proposed. The observer part that provides the best estimate of the vessel position and heading is used in closed-loop control, thereby allowing for improved transient response while maintaining good steady-state performance. Figure 43 shows a block diagram for a general hybrid control system for marine vessels. The performance of the proposed observer is

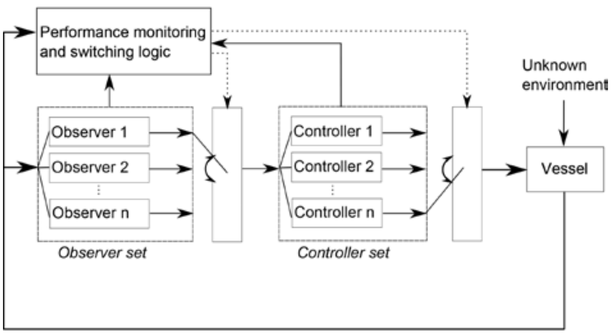


Figure 43: General hybrid control system structure for marine vessel.

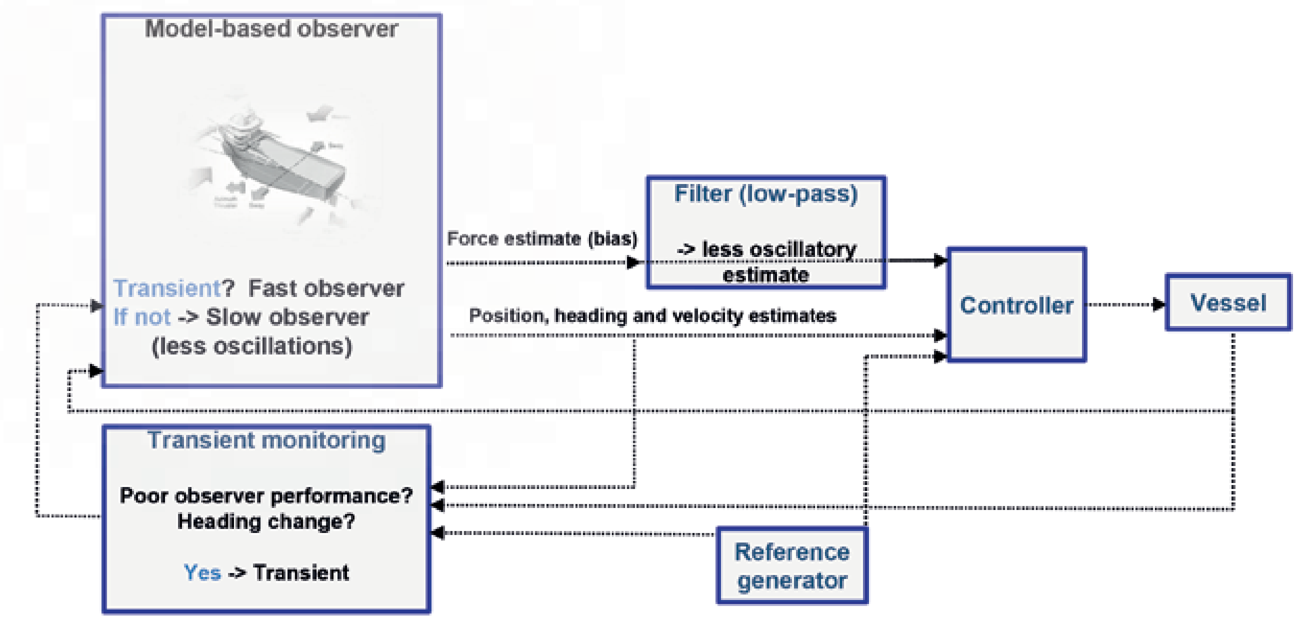


Figure 42: Conceptual drawing of the output feedback transient controller.

demonstrated in model-scale experiments and on full-scale field data. The observer has global stability properties.

In the dynamic positioning of surface vessels, handling transient events is important for good station keeping, especially in rough weather. To address this problem, a time-varying model-based observer that is fast in transient conditions and slower and less oscillatory in steady state is proposed; see Figure 42. To achieve fast compensation of the environmental forces, the force estimate from the observer is used in the controller. However, since this force estimate can be quite oscillatory, it is passed through a low-pass filter before it is used in the controller. Overall, the design gives an output-feedback control system that achieves both good transient and stationary performance.

A system of spatially distributed accelerometers has been used to gather ice-induced acceleration on several ships travelling in the Arctic. The data have been used to derive algorithms for the detection of changes in sea ice conditions, e.g., drift and strength. These algorithms, combined with techniques from extreme value analysis, can be used for the prediction of future ice loads based on statistical models. A thruster-assisted position mooring (TAPM) in sea ice will benefit from early change detection of ice conditions and the prediction of upcoming extreme ice loads.

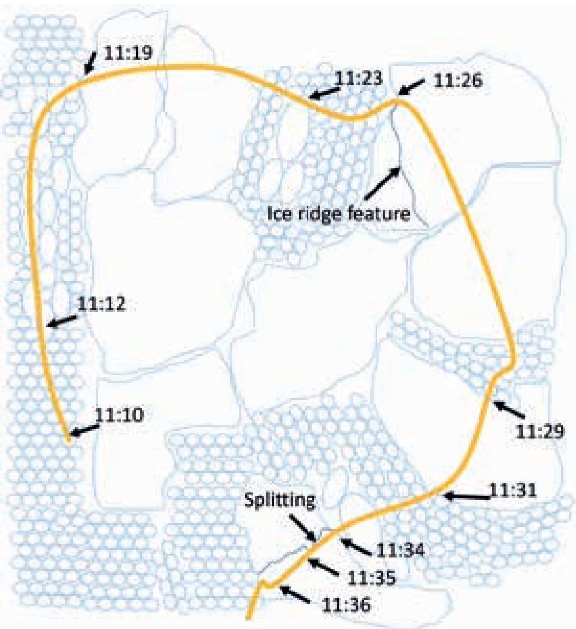
A novel ice load measurement system based on spatially distributed accelerometers has been developed. Algorithms based on statistical change detection enable the detection of changes in the surrounding ice conditions. Extreme value statistics are used to predict upcoming extreme ice load events. These detectors and predictors are useful for control systems of proactive thruster-assisted position mooring in sea ice. Full-scale measurements have been used to verify the algorithms; see Figure 44.

Selected references:

P7.R1. **Greco, Marilena; Colicchio, G; Lugni, Claudio; Faltinsen, Odd Magnus.** 3D Domain Decomposition for Violent Wave-Ship Interactions. International Journal for Numerical Methods in Engineering 2013 ;Volume 95.(8) p. 661-684

P7.R2. **Shao, Yanlin; Faltinsen, Odd Magnus.** A harmonic polynomial cell (HPC) method for 3D Laplace equation with application in marine hydrodynamics. Journal of Computational Physics 2014 ;Volume 274. p. 312-332

P7.R3. **Bardazzi, A; Lugni, Claudio; Antuono, M; Graziani, G; Faltinsen, Odd Magnus.** Generalized HPC method for the Poisson equation. Journal of Computational Physics 2015 ;Volume 299. p. 630-648



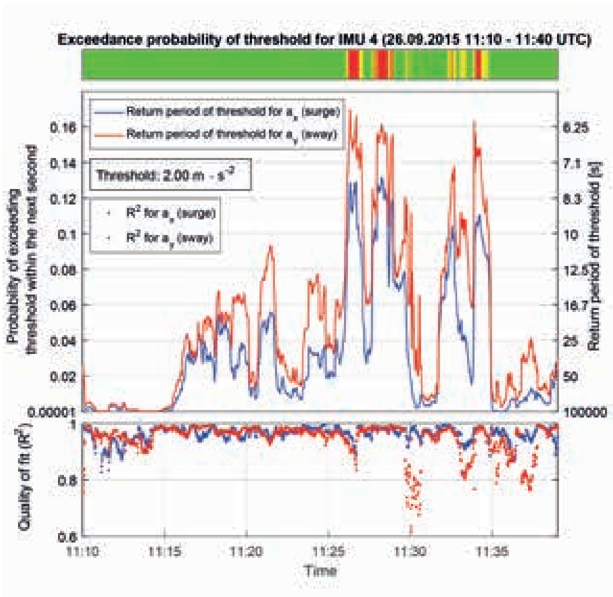


Figure 44: Left: Ice field corresponding to right panel. Right: Estimation of the return period for extreme ice-induced accelerations.

P7.R4. **Greco, Marilena; Lugni, Claudio; Faltinsen, Odd Magnus.** Can the water on deck influence the parametric roll of a FPSO? A numerical and experimental investigation. European journal of mechanics. B, Fluids 2014 ;Volume 47. p. 188-201

P7.R5. **Greco, Marilena; Lugni, Claudio; Faltinsen, Odd Magnus.** Influence of motion coupling and nonlinear effects on parametric roll for a floating production storage and offloading platform. Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences 2015 ;Volume 373.(2033)

P7.R6. **Faltinsen, Odd Magnus; Timokha, Alexander.** On damping of two-dimensional piston-mode sloshing in a rectangular moonpool under forced heave motions. Journal of Fluid Mechanics 2015 ;Volume 772. p. R1

P7.R7. **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)

P7.R8. **Lugni, Claudio; Bardazzi, A.; Faltinsen, Odd Magnus; Graziani, G.** Hydroelastic slamming response in the evolution of a flip-through event during shallow-liquid sloshing. Physics of fluids 2014 ;Volume 26.(3). p. 032108

P7.R9. **Wei, Zhi-Jun; Faltinsen, Odd Magnus; Lugni, Claudio; Yue, Qian-Jin.** Sloshing-induced slamming in screen-equipped rectangular tanks in shallow-water conditions. Physics of fluids 2015 ;Volume 27. p. 032104

Consequences of accidental and abnormal events on ships and offshore structures

Project manager: Prof. Jørgen Amdahl
Scientists: Profs. Marilena Greco, Asgeir J. Sørensen, Torgeir Moan and Odd M. Faltinsen, Adjunct Prof. Claudio Lugni, Dr Ekaterina Kim, Dr Giuseppina Colicchio, Dr Yanyan Sha
PhD candidates: Zhaolong Yu, Woongshik Nam, Daniele Borri, Martin Storheim
Website: www.ntnu.edu/amos/project-8

There is an increasing trend of extending marine activity into deeper and harsher environments, e.g., in conjunction with offshore oil exploitation, offshore wind energy and fish farming. The activity in Arctic areas has increased, accelerated by the effects of global warming. The number and size of support vessels servicing installations have increased, and the risk of collision must be considered in the design stage and during operation. In the low temperatures of the Arctic, darkness and remoteness from infrastructure and search and rescue services increase the potential consequences of accidents in terms of loss of lives, property damage and environmental pollution. Collisions with ice floes and icebergs represent another challenge. Low temperatures may cause steel to become more prone to brittle fracture, thus degrading the structure's robustness to the effects of accidents. The nonlinear finite element method is widely used to analyse the structural behaviour during accidental actions because of its capability to trace the structural collapse accurately, including initiation and propagation of fractures. However, for large structures analysed with shell finite elements, the mesh size must be relatively large to keep the CPU consumption at affordable levels. Models must therefore be developed that capture ductile fracture and brittle fracture for large shell elements. For abnormal ice impacts, where large structural deformations are accepted, provided that the integrity with respect to hydrostatic stability and environmental pollution is not impaired, the interaction between structural deformation, ice deformation and hydrodynamic forces represents another challenge, which requires the development of new ice material models. In addition, for coastal structures, e.g., ultra-large bridges, ship collision must be considered. Underwater explosions represent an important accident scenario and can lead to local and global consequences for nearby structures. Their analysis should properly account for the fluid-structure interaction. Oil booms are often used to contain and recover spilled oil; however, in strong current and severe waves, their efficiency degrades, and large quantities of oil may escape. There is a need for improved design and for defining clear operational limits.

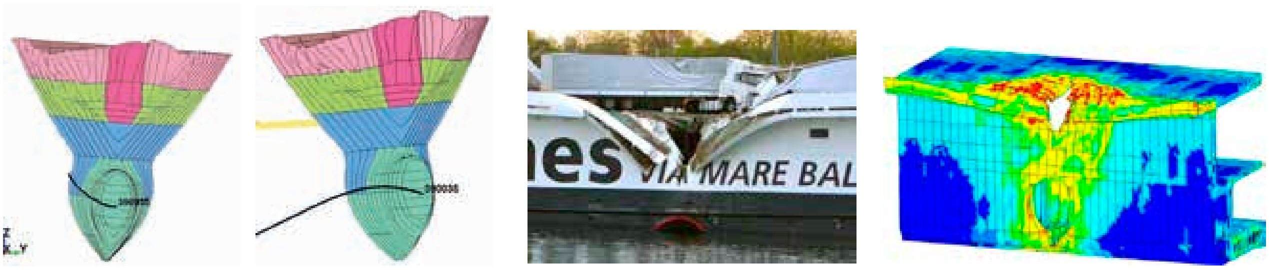
Associated project

Coastal Highway Route E39
Project management: Norwegian Public Road Administration 2013-2016
Involved postdocs: 1

The Norwegian Public Roads Administration is planning to build a new coastal highway, Route E39, along the Norwegian west coast from Kristiansand to Trondheim. The background for the project is that previous studies show that, compared with ferry crossings, fixed crossings can stimulate the development of trade and industry along the E39 route. The project includes replacing existing ferry connections with fixed installations of bridges or tunnels. In total, eight new bridges or tunnels will be built along the route. As most of the fjords are wide and deep, structures with large spans will be designed and installed across the fjords. The new installations can substantially increase the transportation efficiency compared to ferries. However, these fixed installations will narrow the navigable waterways in the fjords. In addition, the structures face the threat of accidental ship collision loads. The consequences of such accidents, including human casualties and financial losses, can be catastrophic. Therefore, bridges or tunnels should be carefully designed for ship collisions.

Main results

Ship collisions and groundings are highly nonlinear, transient, coupled dynamic processes involving large



1 2 3 4

Figure 45: Panels 1 and 2: collision of a ship with a semis-submersible column. 1: early stage with rolling and yawing away from platform. 2: later stage with rolling back and hitting the platform. The yellow beam in the rear represents the hull girder motion. Panels 3 and 4: collision between the Ropax vessel URD and the ferry Nils Holgerson. 3: actual damage. 4: simulated damage to ship side.

structural deformations and fluid-structure interactions. A beam model with hull girder forces based on potential flow theory, including the forward speed effect, was implemented in the nonlinear finite element code LS-DYNA [P8.R1]. Together with a detailed shell finite element model of the structure in the contact area, the code facilitates the assessment of local damage evolution interacting with a six-degree-of-freedom dynamic simulation of global ship motion (see panels 1 and 2 of Figure 45). For typical collision speeds, the forward speed effect is limited and may be neglected. Comparisons against the external-mechanics decoupled method showed that this simplified approach predicts the dissipated energy quite well up to the end of the first impact period, but it does not handle secondary impacts.

A novel method of separating mesh scale effects due to geometric changes and material necking in NLFEA was developed for **fracture analysis** [P8.R2]. An existing fracture criterion (the BWH criterion) was extended beyond the onset of instability, where local necking was assumed to occur within a region equal to the plate thickness. The model facilitates the use of relatively coarse shell elements and enables simulations of large-scale collisions. A large number of fracture models were compared with a series of small- and large-scale fracture and collision tests. No fracture model performed best in all the tests; in addition, 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 (see panels 3 and 4 of Figure 45).

Steel structures subjected to cryogenic spills or operating in arctic conditions will be **exposed to low temperatures**, which may be in the range of the brittle or ductile-brittle transition temperature (DBTT) for steel. The brittleness of the material under such conditions may impair the crashworthiness considerably. Using fine volume elements corresponding to the grain size of the material, the energy absorption in Charpy V-tests at various temperatures was simulated with good accuracy by the RKR brittle fracture model developed by Ritchie, Knott et al. (1973); see Figure 46.

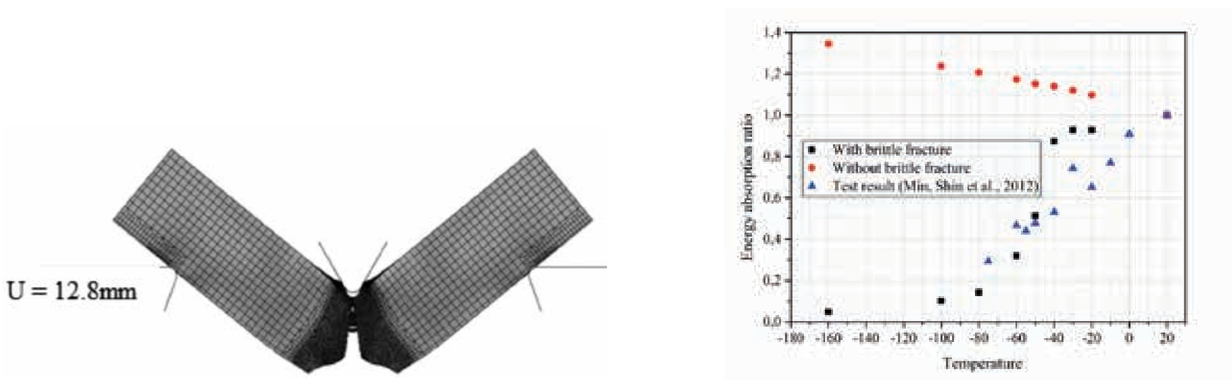


Figure 46: Left: Simulation of Charpy-V test at --20°C. Right: Energy dissipation versus temperature.

The **response of offshore structures to ship impact** was investigated numerically [P8.R3]. Emphasis was given to the interaction between the deformations of ships and platforms. It was found that the resistance to collision can be increased substantially provided that strength design is considered. To achieve this, jacket braces or stiffened panels in the floating platform must fulfil certain compactness requirements. The present work was coordinated with the DNV GL JIP on a revision of the recommended practice for *Determination of Structural capacity with Nonlinear Finite Element Methods.* Several results from this research are used in the on-going extensive revision of DNV GL recommended practice for *Design against Accidental Loads.*

Accidental limit state analysis of ship-iceberg impacts has not reached the same level of maturity as ship-ship collisions because ice material models are much less developed and because ice-crushing characteristics depend on the confinement created by the deforming structure. The fluid-ice-structure interaction can be analysed with the constant added mass (CAM) method and the fluid-structure interaction (FSI) method, where the surrounding fluid flow is directly simulated. The objective of the research was to compare the two methods and to explain the differences in the results. A unique laboratory test for collisions between a freshwater ice mass and a floating steel structure was analysed with LS-DYNA by the Arbitrary Lagrangian Eulerian (ALE) method [P8.R4]. The behaviour of the ice mass was modelled by an elliptic yield criterion and a strain-based pressure-dependent failure criterion that was calibrated against laboratory and in situ tests. The fluid model in the LS-DYNA was verified by comparing the added mass coefficients for a spherical body and a rectangular block with the corresponding WADAM results. Comparison with the test showed that the FSI method yields better results for the motion of the floater, and the relative velocity was in reasonably good agreement with experimental measurements. The CAM method was faster but predicted a higher peak contact force and more dissipated energy in the ice mass compared to the FSI method.

Ship collision analysis of fjord crossings has to be conducted on two levels: local damage analysis of the contact zone and global analysis of the entire structure; see Figure 47. For the floating bridge concept across Bjørnefjorden, local analysis was conducted on the bridge deck girder subjected to accidental impact from the bow of a passenger vessel that failed to pass through the opening under the cable-stayed bridge. Local damage assessment of the bow and the deck girder was conducted with LS-DYNA based on a detailed shell finite element model of the ship bow and the deck girder. Force-deformation curves from the local analysis were modelled as a nonlinear spring in the space frame model of the bridge for the global analysis that was conducted with USFOS. The local analyses indicated that the ship girder will experience acceptable damages for collision energies up to 300 MJ. However, it remains to verify that the global resistance is sufficient and that the residual strength of the entire bridge in the damaged condition subjected to environmental loads is adequate.

Oil spills from ships or marine structures represent a huge risk to the environment and a great cost issue. **Oil booms** are a valuable recovering device but can experience failure with oil escapes in strong currents and severe waves. Two experimental campaigns have been conducted at CNR-INSEAN on an idealized rigid boom consisting of an outer floater and a skirt in a tank filled with water and with a layer of oil on one side. The tank was excited with a long sway period. A basic boom geometry was studied first, with the device partially free to move or fixed (Figure 48). Then, two additional fixed geometries were examined. This enabled the assessment of the influence of body shape and motions on the failure occurrence and both its features and severity.

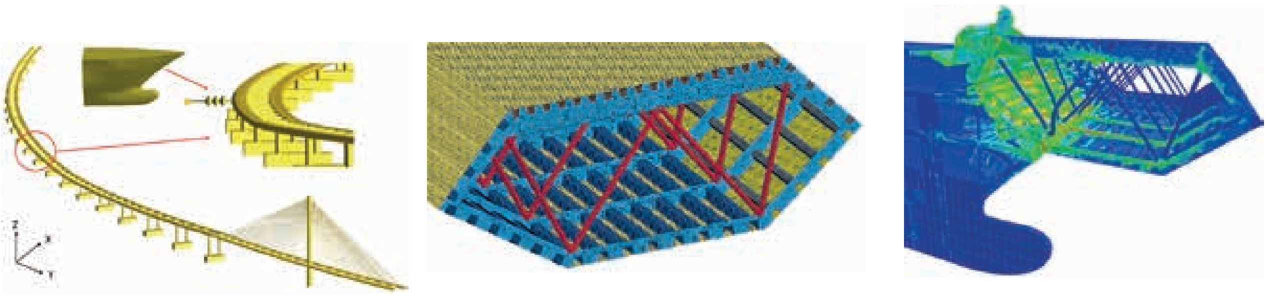
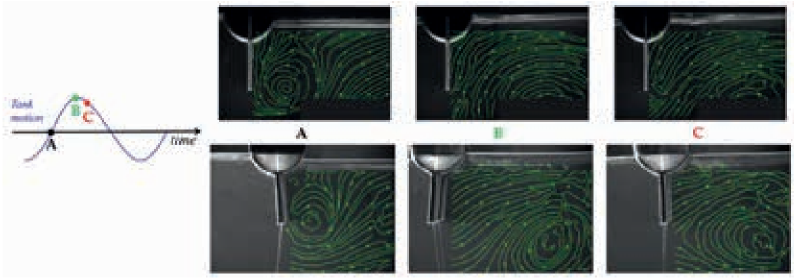


Figure 47: Left: Global finite element model of the bridge. Middle: Detailed shell model of the deck girder. Right: Simulated damage to the bow and the bridge girder.



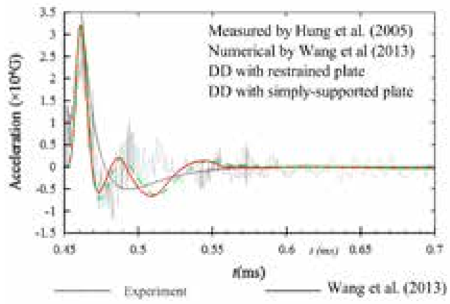


Figure 48 (left): Experiments of an oil boom in a tank in harmonic sway motion with amplitude 1.9 times the floater diameter. Left: motion of the tank with three highlighted time instants. Right: snapshots of the flow evolution for the fixed (top) and moving (bottom) boom basic model. The solid green lines are streamlines, and the arrows indicate the local flow direction. The time instants correspond to those labelled on the left of the figure. ***Figure 49 (right):*** *Underwater explosion as in the experiments of Hung et al. (2005): evolution of the acceleration at the centre of the plate.*

In general, for the studied cases, the moving boom was associated with more pronounced failure events than the corresponding fixed geometry. The analysis of the results is on-going and is relevant for booms in slowly varying currents.

Historically, **underwater explosions** (UEs) have been investigated for their huge military relevance; however, they also remain an important issue for civil marine applications. As an example, UEs can occur near or on oil-gas plants due to severe environmental conditions or human error. The effects of an underwater explosion on an elastic plate of a surrounding structure (e.g., a ship) were investigated numerically through a dynamic domain-decomposition (DD) strategy. The three-dimensional features of the problem require a large computational effort. This effort is reduced through a weak coupling between a one-dimensional radial blast solver, which resolves the blast evolution far from the boundaries, and a three-dimensional compressible flow solver used where the interactions between the compression wave and the boundaries occur and the flow becomes three dimensional. Figure 49 shows the evolution of the acceleration at the centre of a plate documented experimentally by Hung et al. (2005) and predicted by the DD solution with full fluid-structure coupling and assuming either a restrained or a simply supported plate. Numerical results by Wang et al. (2013), employing an analytical technique for the fluid-dynamic problem and an elastic dynamic response, are also reported. The DD consistently reproduces the rising phase of the measured acceleration and captures the inception of oscillations, which characterize the experimental data.

In the studied applications, the limits of the commonly used superposition principle for calculating the wave reflection from structures and the need for strong fluid–structure coupling to capture the possible inception of cavitation correctly [P8.R5] have been highlighted.

Selected references:

P8.R1. **Yu, Zhaolong; Shen, Yugao; Amdahl, Jørgen; Greco, Marilena.** Implementation of Linear Potential-Flow Theory in the 6DOF Coupled Simulation of Ship Collision and Grounding Accidents. Journal of Ship Research 2016 ;Volume 60.(3) p. 1-26

P8.R2. **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 883. p. 59-75

P8.R3. **Storheim, Martin; Amdahl, Jørgen.** Design of offshore structures against accidental ship collisions. Marine Structures 2014 ;Volume 37. p. 135-172

P8.R4. **Song, Ming; Kim, Ekaterina; Amdahl, Jørgen; Ma, Jun; Huang, Yi.** A comparative analysis of the fluid-structure interaction method and the constant added mass method for ice-structure collisions. Marine Structures 2016 ;Volume 49. p. 58-7

P8.R5. **Colicchio, Giuseppina; Greco, Marilena; Brocchini, Maurizio; Faltinsen, Odd Magnus.** Hydroelastic behaviour of a structure exposed to an underwater explosion. Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences 2015 ;Volume 373:20140103.(2033)

Safety, risk and autonomy in subsea intervention

Project manager: Prof. Ingrid Schjølberg
Scientists: Profs. Ingrid B. Utne, Thor I. Fossen, Tor Arne Johansen and Tor B. Gjersvik
PhD candidates: Erlend K. Jørgensen, Ole A. Eidsvik, Christopher Thieme, Jeevith Hedge, Eirik H. Henriksen, Bård B. Stovner
Website: www.ntnu.edu/amos/project-9

The main research challenges of subsea intervention are due to efficiency requirements to reduce operational costs, and autonomy, navigation and guidance are key technologies for addressing this challenge. Moreover, methods for decision support for safer, smarter and more reliable autonomous subsea intervention is needed. This project will address topics in the whole decision support chain, from operator situational awareness to local autonomous functionalities. The research focus is related to all operational aspects such as methods for risk modelling and analysis. Technologies for positioning and localization are essential for local navigation in the vehicle approach to a subsea infrastructure and during intervention. Additionally, methods for estimating cable and environmental forces on an ROV are needed in autonomous control functions. An operator will always be in the loop, and architectures and methods for shared control are required. The project will employ sensor platforms from various NTNU-lab facilities, i.e., AUR-lab, and is closely linked with the activities of NTNU AMOS project 3, 4 and 5.

Associated project

Next generation subsea inspection maintenance and repair operations (NextGenIMR)
Programme: RCN PETROMAKS 2 (2014-17)
Project manager: Prof. Ingrid Schjølberg
Involved PhD candidates and postdocs: 3 PhD candidates and 1 postdoc

NextGenIMR is coordinated by the Department of Marine Technology at NTNU. Their industrial partners are FMC Technologies and Statoil, and SINTEF ICT is a research partner. The development of subsea facilities, including infrastructure and processing equipment, is important for achieving increased efficiency in future oil and gas production. Next-generation subsea factories will constitute complex installations including pump stations, compressors, storage tanks etc. Current and future inspection, maintenance and repair operations are vessel dependent and must be safe and reliable, as they are costly and dependent on open weather windows.

NextGenIMR has developed robust positioning and localization methods and collision-free motion planning algorithms for autonomous subsea inspection and light intervention operations. The project also focuses on subsea factory design for autonomous intervention. The project in particular addresses autonomous platforms; however, the results are also applicable to cable-connected ROVs where operation will shift from manual to automatic control with autonomous functions. Advances in sensor technology, communications, ICT architecture design, localization methods, robotics and task planning present new possibilities to bridge the gap between manual control and autonomy. 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 operations in aquaculture and deep sea mining.

Main results

Three-stage filter for underwater position and velocity estimation
Scientists: Profs. Tor A. Johansen, Thor I. Fossen and Ingrid Schjølberg
PhD candidates: Bård B. Stovner, Erlend K. Jørgensen

Underwater positioning and localization is a challenge, as there is no available GNNS in the deep oceans. A novel three-stage filter has been applied for the estimation of the position and velocity of an underwater vehicle using range measurements from a low-cost acoustic system. The filter is presented in Stovner et al. (2016). In Jørgensen et al. (2016), three methods of improving the robustness of the filter towards pseudo-range measurement noise is presented. This is essential in, for example, acoustic underwater positioning, where temperature layers and salinity may introduce transmission errors. First, as almost all underwater vehicles have a pressure sensor that relates directly to depth, the depth measurement can be used in the algebraic transformation. This significantly increases robustness towards pseudo range measurement noise and also increases robustness regarding transponder placement in the z-direction. Second, as the noise in the quasi-linear measurement model increases linearly with pseudo-range due to the nonlinear transformation of the pseudo-range measurement in the C-matrix, it is suggested to use a calculated algebraic solution for the position and unknown parameter as the measurement instead. This solution is available in Stovner et al. (2016) as a part of calculations on the quasi-linear measurement, and it leads to a linear measurement model with a covariance matrix that is more complicated but smaller in magnitude. Third, a suggested improvement is to add an extra step before the first KF by solving an optimization problem resulting in a decrease in measurement bias. The proof of concept is presented, and the results are verified through simulations. Experiments for evaluation and verification are planned for 2017.

Selected publications:

- **Stovner, Bård Bakken; Johansen, Tor Arne; Fossen, Thor I.; Schjølberg, Ingrid.** Three-stage filter for position and velocity estimation from long baseline measurements with unknown wave speed. American Control Conference (ACC) 2016 p. 4532-4538
- **Jørgensen, Erlend Kvinge; Johansen, Tor Arne; Schjølberg, Ingrid.** Enhanced Hydroacoustic Range Robustness of Three-Stage Position Filter based on Long Baseline Measurements with Unknown Wave Speed. IFAC-PapersOnLine 2016 ;Volume 49.(23) p. 61-67

Time domain modeling of ROV umbilical using beam equations

Scientist: Prof. Ingrid Schjølberg

PhD candidate: Ole A. Eidsvik

The work includes the development of a finite element model for representing the cable dynamics of a typical ROV (Remotely Operated Vehicle) umbilical (Eidsvik (2016)). The goal is to produce a model that is able to capture the most important dynamic effects of the umbilical affecting the ROV by solving the Euler-Bernoulli beam equations using the finite element method. The model is general and is applicable to a wide variety of deep-sea ROV systems. The presented model is demonstrated by numerical examples for umbilical and ROV systems, both for steady state and dynamic responses. The model is further validated by comparison with published results. Figure 50 illustrates how the cable dynamics have a significant effect on ROV motion and the requirements that this sets for autonomy.

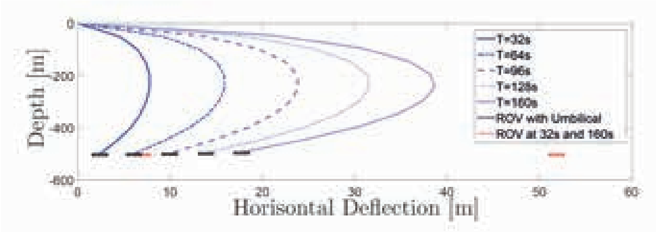


Figure 50: *Cable effects on ROV displacement.*

Related publication:

Eidsvik, Ole Alexander Nørve; Schjølberg, Ingrid. Time Domain Modeling of ROV Umbilical using Beam Equations. IFAC-PapersOnLine 2016 ;Volume 49.(23) p. 452-457

Flexible joystick control system for underwater remotely operated vehicles

Scientists: Profs. Ingrid Schjølberg and Tor B. Gjersvik (NTNU IPT)

PhD candidate: Eirik H. Henriksen

Shared control is a stepping stone towards autonomy in subsea intervention. Current ROVs used for inspection, maintenance and repair tasks of subsea petroleum facilities are often operated with a low level of automation. A properly designed automation system has the potential to lower the required skill and experience level for the operator, increase operation efficiency and counteract operator fatigue. This work applies theory from the development of human centred automation in the aviation industry to propose a new human-centred control system enabling shared control of ROVs.

The shared control system is implemented in a simulator and evaluated qualitatively. The system includes four modes of operation: position control, object of interest orbit control, autopilot mode, and waypoint guidance mode (Henriksen 2016a). An open-source simulation environment for underwater vehicles and robots is developed in MORSE. The simulation environment allows the user to simulate underwater robotic vehicles with realistic dynamic behaviour in a 3-dimensional virtual environment. The environment is highly configurable and offers a set of modules for simulating different types of vehicles in a number of underwater scenarios (Henriksen 2016b).

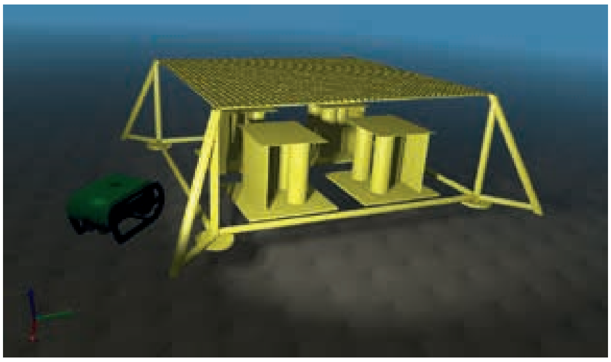


Figure 51: Screenshot from UW Morse Simulator.

Related publications:

- (a) **Henriksen, Eirik Hexeberg; Schjølberg, Ingrid; Gjersvik, Tor Berge Stray.** Adaptable Joystick Control System for Underwater Remotely Operated Vehicles. IFAC-PapersOnLine 2016 ;Volume 49.(23) p. 167-172
- (b) **Henriksen, Eirik Hexeberg; Schjølberg, Ingrid; Gjersvik, Tor Berge.** UW MORSE - The UnderWater Modular Open Robot Simulation Engine. IEEE / OES Autonomous Underwater Vehicles. Proceedings 2016 p. 261-267

Safe and reliable operation of autonomous vehicles and vessels

Scientists: Profs. Ingrid B. Utne and Ingrid Schjølberg
PhD candidate: Christoph Thieme

The main focus has been the process for developing safety indicators for the operation of autonomous marine systems (AMSs), which has been published in Reliability Engineering and System Safety (Thieme 2016). The conditions of safety barriers and principles from resilience engineering constitute the basis for the development of safety indicators. This article focuses on the importance of identifying safety indicators early in the system life cycle, as well as implementation and follow up during operation. The indicators reflect safety in AMS operation and can assist in the planning of operations, in daily operational decision making, and in identifying potential improvements in operation. The development process and implementation are demonstrated for an autonomous underwater vehicle (AUV), but the process is valid for other types of AMSs as well. The case study demonstrates that the proposed process leads to a comprehensive set of safety indicators, which are expected to contribute to the safer operation of current and future AMSs.

Related publication:

Thieme, Christoph; Utne, Ingrid Bouwer. Safety performance monitoring of autonomous marine systems. Reliability Engineering & System Safety 2017 ;Volume 159. Suppl. March p. 264-275

Safety and reliability of marine underwater autonomous vehicles

Scientists: Profs. Ingrid B. Utne and Ingrid Schjølberg
PhD candidate: Jeevith Hedge

The focus of this work is the development of collision risk indicators applicable to autonomous remotely operated vehicles (AROVs) (Hedge (2016)). Such indicators are essential for promoting situational awareness in decision support systems. The work has recently been published in the journal Loss Prevention in the Process Industries. Three suitable risk-based collision indicators are suggested for AROVs, and the indicators are classified as having different thresholds: low, intermediate and high. To gather input data for the proposed indicators, an AROV flight path is simulated, and three collision targets are established, i.e., subsea structure, seabed and a cooperating AROV. The proposed indicator development method, together with the case study, shows that indicators can identify risk-prone waypoints in the AROV path. The method produces an overall risk picture for a given AROV path, which may provide useful input in the planning of mission paths and for the implementation of risk-reducing measures. Although the work focuses on collision risk, the method may be used for other accident scenarios for AROVs.

Related publication:

Hegde, Jeevith; Utne, Ingrid Bouwer; Schjølberg, Ingrid. Development of collision risk indicators for autonomous subsea inspection maintenance and repair. Journal of Loss Prevention in the Process Industries 2016 (44) p. 440-452

RESEARCH COLLABORATION ACROSS RESEARCH GROUPS

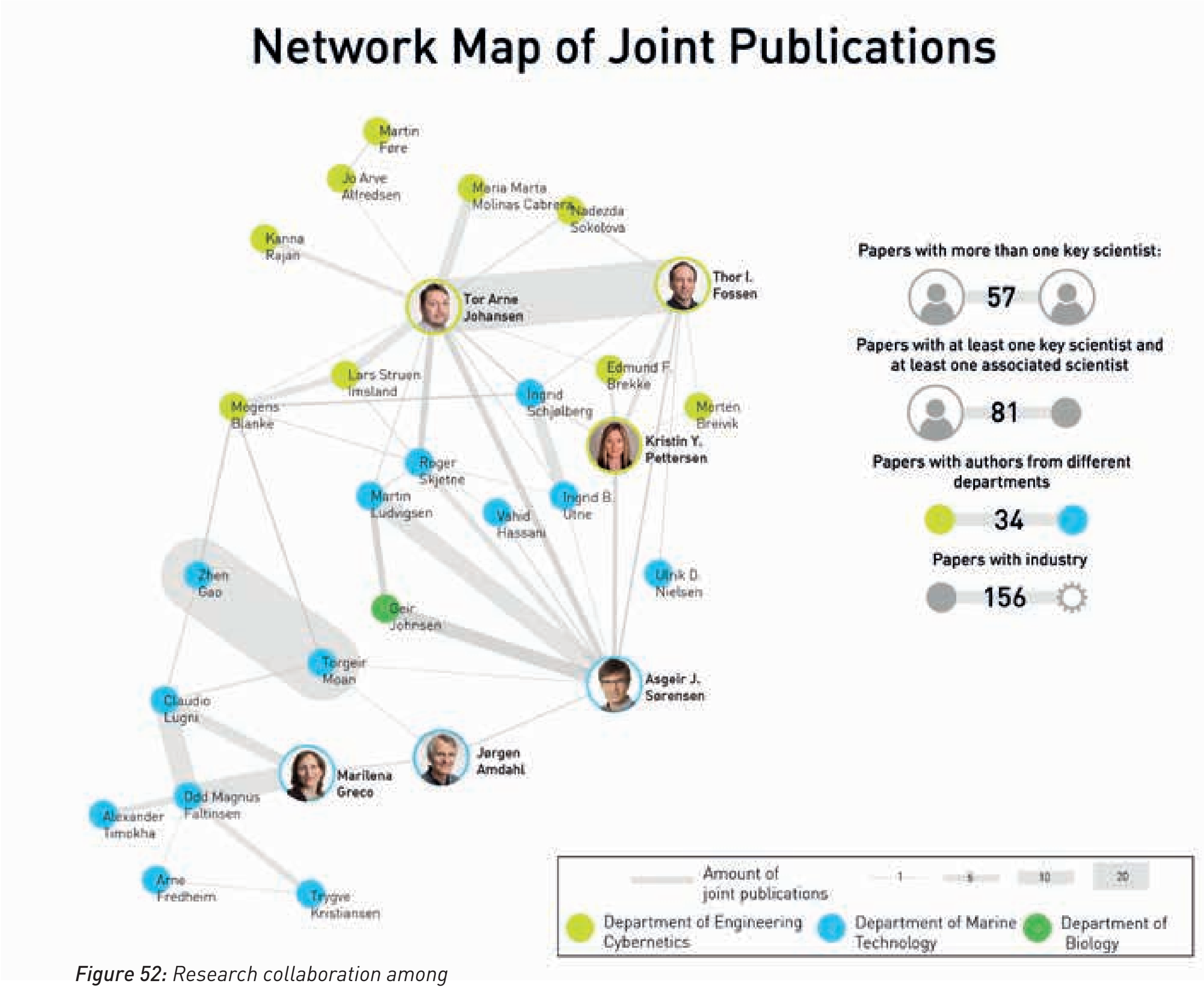


Figure 52: *Research collaboration among research groups.*

The research from the first five years is organized into nine projects within the following two research areas:

- Autonomous unmanned vehicles and operations
- Smarter, safer and greener marine operations and systems

In addition, several associated research projects were established in cooperation with affiliated scientists and collaborators.

The scientific publications are within the knowledge fields of hydrodynamics, structural mechanics, guidance, navigation and control theory and autonomous systems.

In addition, marine biology and oceanography in terms of mapping and monitoring using marine robotics have become new knowledge fields of NTNU AMOS. Figure 52 shows how interdisciplinary research illustrated by joint publications among the key scientists as well as affiliated scientists have been carried out over the first 4 years of operation.

Even though interdisciplinary research is evident in NTNU AMOS, we observe potential for even better interaction between researchers from different knowledge fields. Aiming for a higher level of autonomy such as cross coupling is needed.

INTERNATIONAL COLLABORATION

Figure 53: Map showing international collaboration by joint publication. At least one author must be affiliated to an international university or research institute.

NTNU AMOS researchers co-operate with many international universities and research institutes, and a regulated agreement for a two-way exchange of senior researchers and PhD candidates, the sharing of research infrastructure, and joint publications was signed with 17 institutions by the end of 2016. In addition to these institutions, NTNU AMOS researchers have published 257 joint publications in the period 2013-2016 with at least one international co-author. Most of the international co-authors have their origin from leading institutions in Asia, Europe and North America. The distribution of joint international papers is illustrated in Figure 53, where Italy, Denmark, Portugal, the USA and France are the top five nations for joint authorship.

INNOVATION AND TRAINING OF PHD CANDIDATES

The motto of NTNU AMOS is to nourish a lively scientific heart, thus giving sustainable value to society. The Centre strives for scientific excellence and at the same time aims to generate a culture of innovation and value creation, all according to our values: excellence, generosity and courageousness.

NTNU AMOS has several innovation areas (see Figure 54), the most important one being our collaboration with the industry. In addition to the NTNU AMOS' partners Statoil, DNV GL, SINTEF Fisheries and Aquaculture, SINTEF ICT and MARINTEK (SINTEF Ocean as of 2017), NTNU AMOS cooperates with the following companies and research institutes:

- 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: Arne Kjørsvik, 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
- Ulstein Group, contact persons: Dr Tore Ulstein, Dr Per Olav Brett

In addition, NTNU AMOS gives advice to governmental agencies within marine science and management, contributes to new methods and technology for research, and creates its own spin-off companies (see the numbers in "Innovation activities at NTNU AMOS" below).

Read more about NTNU AMOS' strategy for the innovation and training of PhD candidates

NTNU AMOS/Ocean School of Innovation

In 2014, the NTNU AMOS School of Innovation was founded. NTNU Technology Transfer AS (TTO) has had a vital role in developing and organizing the innovation school along with the Centre's management team. Many PhD candidates have participated in the school's courses and innovation lunches since then. The concept was so successful that in 2016, the NTNU AMOS School of Innovation expanded and changed its name to NTNU Ocean School of Innovation, which now also includes the Centres for Research-Based Innovation (SFI) Exposed, Move, Smart Maritime and SAMCoT. The actions of the NTNU Ocean School of Innovation in 2016 are listed in the appendices of this annual report under "Innovation".

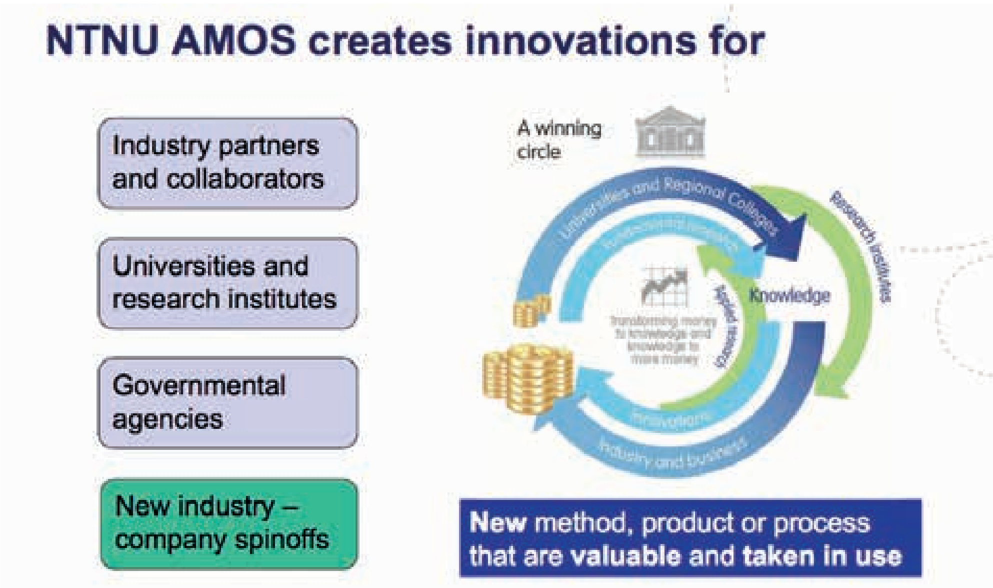


Figure 54: The NTNU AMOS' innovation areas.

Innovation activities at NTNU AMOS

NTNU AMOS spin-off companies: 3
Projects for the commercialization/verification of technologies and licensing agreements: 4
Patents at NTNU AMOS: 5
Courses by NTNU AMOS/Ocean School of Innovation for NTNU AMOS PhD candidates: 6
NTNU AMOS Innovation Lunches for NTNU AMOS PhD candidates: 8

Two new technology verification projects at NTNU AMOS in 2016

NTNU AMOS, together with the NTNU Oceans School of Innovation and NTNU Technology Transfer, has a clear ambition to transform the research results into innovation and commercialization. As a result, we have been awarded two new technology verification projects, funded by the Research Council of Norway's FORNY program, in December 2016.

SCOUT – Drone Inspection Concept
This project will pursue the industrial verification of autonomous navigation, control and data management by using drones for industrial inspection, in collaboration with the NTNU AMOS partners DNV GL and Statoil. The project aims to demonstrate the significant improvements in inspection data quality, to provide more user-friendly and safer operations for drone inspections and to open new market opportunities by enabling a higher level of autonomous inspection services when operating close to structures. The concept builds on the technology platform developed by PhD candidate Kristian Klausen and others at NTNU AMOS. The project manager is Maja Andersen at TTO.

D-ICE - Autonomous ice detection and mitigation for UAVs
Icing on unmanned aircraft is currently one of the main hazards and unsolved challenges for aircraft operating in the harsh maritime climates, not only in Norway but also globally. The project builds on the research results of PhD candidates Kim Sørensen and Kasper Borup, who have developed methods for the detection and mitigation of icing on exposed surfaces of unmanned aircraft based on an electro-thermal principle and autonomous control. The UAV-Lab at NTNU AMOS is the first in the world to prove this concept in UAV test flights, in collaboration with NASA, Ames and others, and is now taking this patent-pending technology to the next level with Norwegian and international partners. The project manager is Kristin Jørstad at TTO.

Figure 55 (left): NTNU AMOS testing UAV technology for inspection of a tank in Njord B with Statoil. Photo: Kristian Klausen, NTNU.
Figure 56: The launch of NTNU's X8 UAV from Ny-Ålesund, Svalbard. Photo: Kjell Sture Johansen, NORUT Tromsø.

DISSEMINATION AND COMMUNICATION

Figure 57: NTNU AMOS employees, associates and partners at NTNU AMOS Days 27 October 2016. Photo: Annika Bremvåg, NTNU.

NTNU AMOS is extremely active in disseminating its research results to other researchers and the general public. In addition to the dissemination occurring throughout scientific publications and presentations, as well as in the education of PhD candidates, postdocs and master students, NTNU AMOS strives to be visible in the media. We also arrange conferences and seminars for both external and internal dissemination purposes. Below are some numbers documenting some of our external dissemination activities so far.

Regarding the internal exchange of knowledge and ideas, the PhD candidates at NTNU AMOS, NTNU's Department of Marine Technology (IMT) and Department of Engineering Cybernetics have been meeting once a week to present their research to each other for many years. We have also started regularly distributing an internal joint newsletter for NTNU AMOS and IMT. Furthermore, NTNU AMOS hosts a kick-off each fall. We have also hosted several celebratory lunches and gatherings throughout the seasons and years. In addition, we arranged a lunch seminar for female 5-grade master students with IMT in November 2016 in order to recruit female PhD candidates. Furthermore, the PhD candidates at NTNU AMOS like to spend their free time together; they ski, have fishing trips, climb, swim or jog. Some play soccer with staff from Marintek and IMT, or they barbecue together. Others make music collectively, go to the cinema, or grab a beer in the evening. Some even participate in marathons and triathlons together. Check out the interviews with PhD candidates in this annual report to learn more about what it is like to be a PhD candidate at NTNU AMOS.

Conferences at NTNU AMOS with external involvement: **8**
Guest lectures: **66**
Popular science publications in newspapers, trade journals, TV, radio, museums and online: **156**

CAMS 2016: 10th IFAC Conference on Control Applications in Marine Systems

The 10th IFAC Conference on Control Applications in Marine Systems (CAMS 2016) occurred 13-16 September 2016 at the Radisson Blu Royal Garden Hotel in Trondheim. Researchers from NTNU AMOS organized the conference, and NTNU AMOS was a co-sponsor. Approximately 150 people from around the world attended the conference.

Find more information on the conference's website
Programme at a glance
Sessions programme

Polar night exhibition at the NTNU University Museum

NTNU AMOS researchers took part in the creation of the exhibition about Polar night studies using underwater robotics which is taking place at the NTNU University Museum 22 September 2016 through May 2017.

Find more information in the exhibition's flyer

Read the interview with NTNU AMOS Director and Professor Asgeir J. Sørensen on NRK.no: Blå lys i kalde svarte dyp, 22 September 2016

NTNU AMOS Days 2016

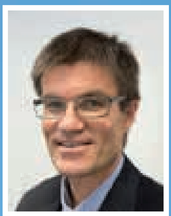
Each year, NTNU AMOS Days take place in October. Over 100 people joined the two-day event on 27-28 October 2016 at Quality Hotel Augustin in Trondheim.

Selected PhD candidates and postdocs presented their research, and NTNU AMOS partners provided their ideas and input.

Find the presentations online
Read the programme

PHOTO GALLERY

Key Scientists



Prof. Asgeir J. Sørensen, Director

Prof. Thor I. Fossen, Co-director

Prof. Jørgen Amdahl

Prof. Marilena Greco

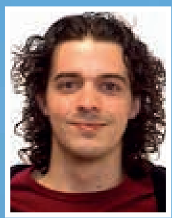
Prof. Tor Arne Johansen

Prof. Kristin Y. Pettersen

Adjunct professors and adjunct associate professors

Prof. Mogens Blanke

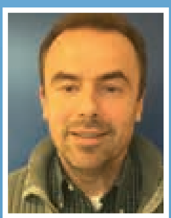
Adj. prof. Arne Fredheim



Adj. ass. prof. Martin Føre

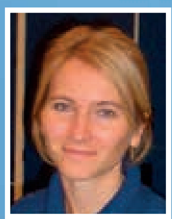
Adj. ass. prof. Vahid Hassani

Adj. prof. Karl H. Johansson



Adj. prof. Claudio Lugni

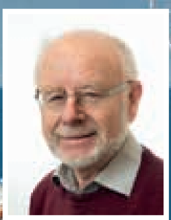
Adj. ass. prof. Ulrik Dam Nielsen



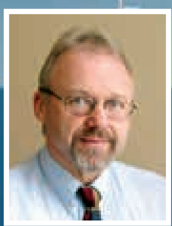
Adj. ass. prof. Nadezda Sokolova

Adj. ass. prof. Rune Storvold

Senior scientific advisers



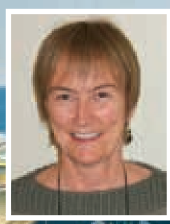
Prof. Odd M. Faltinsen



Prof. Torgeir Moan

Administration

Annika Bremvåg

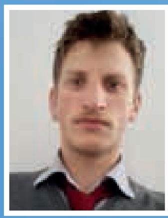


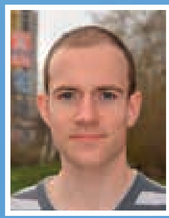
Sigrid Bakken Wold

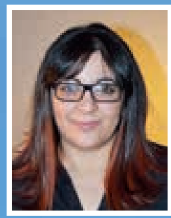
Postdocs/researchers


Dr Konstantin Amelin


Dr Zhengshun Cheng

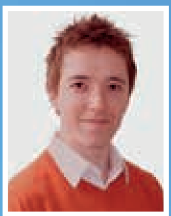

Dr Andrea Cristofaro


Dr Mark Haring

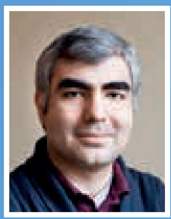

Dr Eleni Kelasidi


Dr Ekaterina Kim


Dr Giorgio K. Kufoalor


Dr Pål Liljebäck

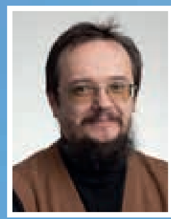

Dr Amir Rasekhi Nejad


Dr Babak Ommani


Dr Damiano Rotondo


Dr Yanyan Sha

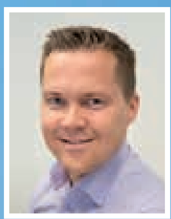

Dr Kim L. Sørensen

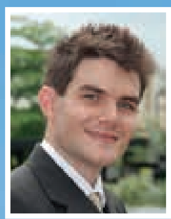

Prof. Oleksandr Tymokha

Affiliated scientists


Ass. prof. Jo Arve Alfredsen


Ass. prof. Erin E. Bachynski

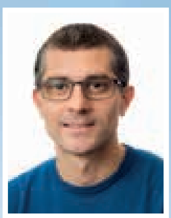

Dr Morten Breivik

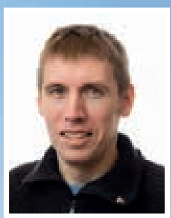

Ass. prof. Edmund Brekke


Prof. Zhen Gao


Prof. Lars S. Imsland


Prof. Geir Johnsen


Prof. Trygve Kristiansen


Prof. Martin Ludvigsen


Prof. Marta Molinas


Prof. Ingrid Schjølberg


Prof. Roger Skjetne


Ass. prof. Annette Stahl


Prof. Ingrid B. Utne

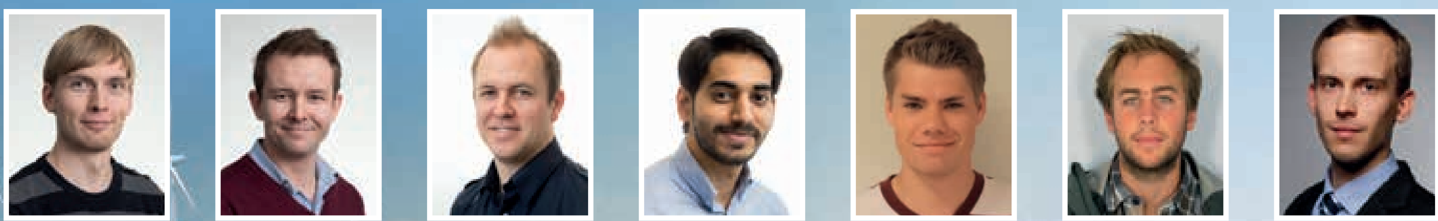
PhD candidates

Inga Aamot | Wilson G. Acero | Anders Albert | Sigurd M. Albrektsen | Leif Erik Andersson | Fabio Andrade | Dennis Belleter

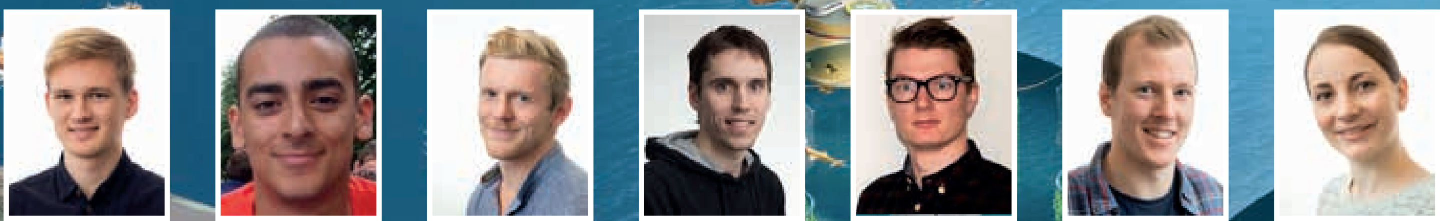
Elias Bjørne | Pål T. Bore | Daniele Borri | Kasper T. Borup | Astrid H. Brodtkorb | Torleiv H. Bryne | Torstein I. Bø

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

João Fortuna | Trygve O. Fossum | Lorenzo Fusini | Mahdi Ghane | Kristoffer Gryte | Giriraja Sekhar Gunnu | Richard Hann



Jakob M. Hansen | Finn-Christian W. Hanssen | Martin Hassel | Jeevith Hegde | Håkon Hagen Helgesen | Eirik Hexeberg Henriksen | Hans-Martin Heyn



Jan-Tore H. Horn | Anthony Hovenburg | Erlend K. Jørgensen | Ulrik Jørgensen | Øivind K. Kjerstad | Kristian Klausen | Anna Kohl

Fredrik S. Leira | Marco Leonardi | Lin Li | Qinyuan Li | Chenyu Luan | Shaojun Ma | Siri H. Mathisen

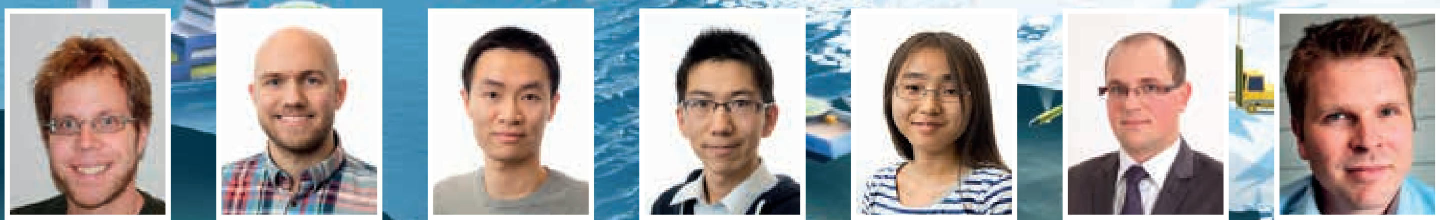
Marianne Merz | Michel Rejani Miyazaki | Signe Moe | Albert Sans Muntadas | Woongshik Nam | Mikkel C. Nielsen | Ingunn Nilssen

Petter Norgren | Stein M. Nornes | Jonatan Olofsson | Claudio Paliotta | Morten D. Pedersen | Zhengru Ren | Christopher D. Rodin

Robert Rogne | Børge Rokseth | Thomas Sauder | Yugao Shen | Mohd A. Siddiqui | Espen Skjong | Emil Smilden

Ming Song | Carlos E. Silva de Souza | Martin Storheim | Bård B. Stovner | Ida M. Strand | Jørgen Sverdrup-Thygeson | Mikkel E. N. Sørensen

Stian H. Sørum | Christoph A. Thieme | Einar S. Ueland | Stefan A. Vilsen | Svenn A. Tutturen Værnø | Ling Wan | Andreas Wenz



Martin S. Wiig | Erik F. Wilthil | Xiaopeng Wu | Zhaolong Yu | Yuna Zhao | Artur Zolich | Øyvind Ødegård

LABORATORY HIGHLIGHTS

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

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

To address challenges in the ocean space, AUR-Lab runs and maintains a park of AUVs, ROVs, instruments, samplers, and navigation equipment with support systems on behalf of partners from five different faculties. The lab represents an interdisciplinary scientific community where scientific questions are addressed by teams with specialists from many areas. Opportunities for faculty, researchers, and both PhD and MSc students to test and experiment are provided enhancing hypotheses and theoretical work. Some of the scientific questions for 2016 have been related to arctic biology and archaeology, system autonomy, and marine mining. The Department of Marine Technology hosts the lab, and the Department of Biology provides facilities at the Trondheim Biological Station.

In 2016, together with the University of Tromsø (UiT) and the University Centre in Svalbard (UNIS), AUR-Lab and NTNU AMOS completed a Polar Night cruise with RV Helmer Hansen on the north side of Svalbard. The marine life in the Polar night was under investigation, and unmanned platforms, such as USVs, AUVs and ROVs, were deployed. During the cruise, shipworms were discovered and caught international attention, as the general concept was that shipwrecks were protected from this threat by the low temperatures. This finding may indicate that less time than previously expected is available to map and document wrecks in arctic waters.

In increasing the utilization of underwater robotic vehicles in science, official management and industry, collaborating systems of unmanned platforms can prove essential. On-board data processing, marine communications and operational complexity are among the issues that must be addressed to realize a scenario of UAVs, USVs and AUVs working together. Together with the Norwegian Defense Research Establishment (FFI), Kongsberg Seatex, Maritime Robotics and the University of Porto, the capabilities of a network of vehicles were tested. AUV Hugin communicated to USV Telemetron and UAV X8 while relaying information back to the operators on board RV Gunnerus. All vehicles were then deployed in a scenario searching for objects on the seabed.

Together with CoE CAGE, AUR-Lab and NTNU AMOS again mobilized on board RV Helmer Hansen for a three-week geology cruise. The CAGE cruise was conducted at 3 methane-rich locations around Svalbard, with the goal of using the ROV SK30k ROV to support an interdisciplinary survey and sampling programme. The project achieved all objectives of the programme, including surveying new areas at both the Storfjordrenna Pingos and Bjørnøyrenna craters and resurveying known areas with high resolution, thereby revealing new seabed features and collecting seabed, water, and gas samples with the ROV with unprecedented precision in relation to methane seeps and other seabed features.

Together with the RCN project MarMine, AUR-Lab organized and led a scientific cruise for the Arctic Mid-Ocean Ridge (AMOR) in August. On board the Offshore Construction Vessel (OCV) Polar King, the operation lasted for three weeks and used ROVs and AUV to sample and map the seabed down to a depth of 3000 metres. The objectives were to collect geological samples for ore characterization and mineral process studies and to provide biological samples and observation for environmental baseline investigations. However, technology development was also in focus – Underwater Hyperspectral Imaging (UHI) testing equipment was mounted on both AUVs for the first time. To provide sub-seabed samples, and ROV-mounted core drilling system was developed and tested on the seabed. The efficiency was high, and during the two weeks on the site, 21 ROV and 9 AUV dives were conducted.

Figure 58: *AUV Hugin HUS on the stinger during recovery on OCV Polar King after a successful dive to 3000 m on the AMOR.*

Figure 59: USV Jetyak in the Polar Night measuring light spectra and acoustic reflections to investigate the vertical migration of zooplankton.

Media coverage:

- Science, In the polar 'twilight zone,' these unusual sea creatures outshine the starlight, 4 November 2016
- Dagens Næringsliv, Gull på havbunnen?, 16 August 2016
- Teknisk Ukeblad, Her er Norge verdensledende. Nå skal vi gjøre det til en milliardindustri, 4 June 2016
- Science, Voyage into darkness, 18 March 2016
- Smithsonian Magazine, "Termites of the Sea" Found Munching Wood Near Arctic Shipwrecks, 1 March 2016
- Science, Arctic shipworm discovery alarms archaeologists, 26 February 2016
- NRK P1 radio, «Polarnatt», God morgen Trøndelag, interview with Prof. Geir Johnsen, 23 February 2016
- Forskning.no, Undervannsrobot som oppfyller tre ønsker, 16 February 2016
- Aftenposten, Nye mysterier avdekkes i Polhavet, 12 January 2016
- Forskning.no, Jan Mayen-forskere fant rester av amerikansk krigsbase, 6 January 2016

Selected publications:

- **Ludvigsen, Martin; Sørensen, Asgeir Johan.** Towards integrated autonomous underwater operations for ocean mapping and monitoring. Annual Reviews in Control 2016 ;Volum 42. s. 145-157
- **Cronin, Heather; Cohen, Jonathan H.; Berge, Jørgen; Johnsen, Geir; Moline, Mark A.** Bioluminescence as an ecological factor during high Arctic polar night. Scientific Reports 2016 ;Volume 6.
- **Berge, Jørgen; Kintish, Eli; Ødegård, Øyvind; Johnsen, Geir.** Arctic shipworm discovery alarms archaeologists. Science [Journal] 2016-02-26

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 (UASs). We are using the Agdenes airfield, located approximately 90 km southwest of Trondheim, as the primary test field. In 2016, we also operated UAVs from Eggemoen and Ny-Ålesund.

Various payload systems have been integrated and used in the Penguin B and X8 fixed-wing UAVs in addition to multi-rotor platforms. The primary payloads in use are thermal cameras, daylight cameras, radio communication payloads, icing protection systems, aerodynamic performance sensor payloads, and advanced navigation sensor suites. Research has also been concentrated on the coordinated control of multiple UAVs for high-precision multi-body operations.

Selected publications:

- **Wenz, Andreas Wolfgang; Johansen, Tor Arne; Cristofaro, Andrea.** Combining model-free and model-based angle of attack estimation for small fixed-wing UAVs using a standard sensor suite. I: *2016 International Conference on Unmanned Aircraft Systems (ICUAS)*. IEEE conference proceedings 2016 ISBN 978-1-4673-9334-8. p. 624-632
- **Mathisen, Siri Holthe; Gryte, Kristoffer; Johansen, Tor Arne; Fossen, Thor I.** Non-linear Model Predictive Control for Longitudinal and Lateral Guidance of a Small Fixed-Wing UAV in Precision Deep Stall Landing. I: *AIAA Infotech at Aerospace 2016:* American Institute of Aeronautics and Astronautics 2016 ISBN 978-1-62410-388-9.
- **Merz, Mariann; Johansen, Tor Arne.** Feasibility study of a circularly towed cable-body system for UAV applications. I: *2016 International Conference on Unmanned Aircraft Systems (ICUAS)*. IEEE conference proceedings 2016 ISBN 978-1-4673-9334-8. p. 1182-1191
- **Rotondo, Damiano; Cristofaro, Andrea; Johansen, Tor Arne; Nejjari, Fatiha; Puig, Vicenç.** Detection of icing and actuators faults in the longitudinal dynamics of small UAVs using an LPV proportional integral unknown input observer. *Elsevier IFAC Publications / IFAC Proceedings series* 2016
- **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 ;Volume 39.(8) p. 1777-1789

Figure 60: NTNU's X8 UAV operating at Svalbard. Photo: Kjell Sture Johansen, NORUT Tromsø.

New model ship at the Marine Cybernetics laboratory (MC-lab)

The lab's webpage: www.ntnu.edu/imt/lab/cybernetics

A new model ship, the C/S Inocean Cat I Drillship (C/S stand for Cyber Ship), has been built for experimentation at the Marine Cybernetics Laboratory (MC-Lab). This vessel is an Inocean design based on Statoil's Cat I drillship concept for Arctic offshore drilling, a DP and turret moored mobile offshore drilling unit capable of operating in up to 1.2 m Arctic level ice. At NTNU AMOS and MC-Lab, we were allowed access to this design and built a scale-model version of the drillship at a scale of 1:90. This gives a ship model with a physical size of 2.58 m, and it is available for research on dynamic positioning and position mooring and related control and hydrodynamics experiments in MC-Lab for our students and researchers.

The vessel hull, which is made out of carbon fibre, was produced by MARINTEK during autumn 2015. The model ship is equipped with the following:

- 6 azimuth thrusters, 3 fore and 3 aft;
- a freely rotatable turret amidships capable of holding up to 8 mooring lines with tension measurements;
- 6-DOF measurements of position and orientation;
- an inertial measurement system with acceleration measurements;
- a control system with functions for manual thruster control, joystick control, dynamic positioning (DP), and thruster-assisted position mooring (TAPM); and
- a watertight lid to keep the instrumentation dry.

The MSc student Jon Bjørnø conducted his master's project in 2015-2016 and followed up the model ship design and specifications, procurement of the parts, and fabrication of the hull, implementated the control system, developed the simulation model, and performed final testing of the thruster-assisted mooring in MC-Lab. The candidate parameterized the numerical simulation model from system identification trials from the MC-Lab and hydrodynamic programmes. In collaboration with Bjørnø, the MSc student Preben Frederich did his master project on the local thruster controls and thrust allocation, where the thruster dynamics were modelled

Figure 61: The Inocean design of Statoil Cat I Arctic drilling unit. Illustration: Inocean.

Figure 62: The model ship C/S Inocean Cat I Drillship in MC-Lab. Photo: Jon Bjørnø, NTNU.

and identified, the local thruster controls were implemented based on rpm measurements, and quadratic programming was employed in the thrust allocation to handle thruster constraints and forbidden thrust sectors.

Find more information on Inocean.no: Inocean won the CAT I drillship design contract from Statoil, 24 September 2013

Selected publications:

- **Bjørnø, Jon.** Thruster-Assisted Position Mooring of C/S Inocean Cat I Drillship. Norges teknisk-naturvitenskapelige universitet 2016, PhD thesis, 149 p.
- **Frederich, P.** Constrained Optimal Thrust Allocation for C/S Inocean Cat I Drillship. Norges teknisk-naturvitenskapelige universitet 2016, Master thesis. 132 p.

Test site for unmanned vehicles opens in the Trondheim Fjord

Figure 63: This is how unmanned ships may look in the future. Illustration: Kongsberg Seatex.

The Trondheim Fjord in Norway will be the world's first technological playground for pilotless vehicles that move below, on and above the water's surface.

Prof. Asgeir J. Sørensen comments: "As far as I know, this is the first test site of its kind in the world. In fact, I'm surprised at how fast the development is progressing. Now that the test site is being established, we have also received the blessing of the Norwegian authorities to try out technology that's going to amaze people."

Media coverage:

- Gemini.no: Test site opens for unmanned vessels, 1 October 2016
- Blog by NTNU AMOS Prof. Ingrid Schjølberg: Trondheimsfjorden et utmerket testområde, 7 October 2016
- Adressa: Først i verden med testområde for ubemannede fartøyer, 30 September 2016
- NRK: Trur på sjølvstyrte ferjer i norske fjordar innan 2020, 30 September 2016
- Bergens Tidende: Slutten for den norske sjømann, 7 November 2016

RESEARCH CAMPAIGNS

Arctic Ocean 2016 expedition

Supervisors: Profs. Roger Skjetne and Sveinung Løset
PhD candidates: Hans-Martin Heyn, Runa Skarbø (CRI CIRFA), Jon Bjørnø (CRI SAMCoT)
Website: http://polarforskningsportalen.se/en/arctic/expeditions/arctic-ocean-2016

The Arctic Ocean 2016 was a 6-week polar research expedition in the Arctic ocean basin using the two ice-breakers Oden and Louis S. St-Laurent in collaboration with Natural Resources Canada and the Swedish Polar Research Secretariat. CRI SAMCoT and CoE NTNU AMOS were invited, and a few positions were available for our researchers. The PhD candidates Hans-Martin Heyn, Runa Skarbø, and Jon Bjørnø, supervised by Prof. Roger Skjetne and Prof. Sveinung Løset, joined the expedition on behalf of NTNU to perform sea-ice data acquisition related to ice management and ice surveillance. Our objective is improved autonomy in Arctic marine operations through the development of algorithms for the online or real-time tracking and prediction of important ice parameters such as sea-ice drift and loads on vessels, ice concentration, and floe size distribution.

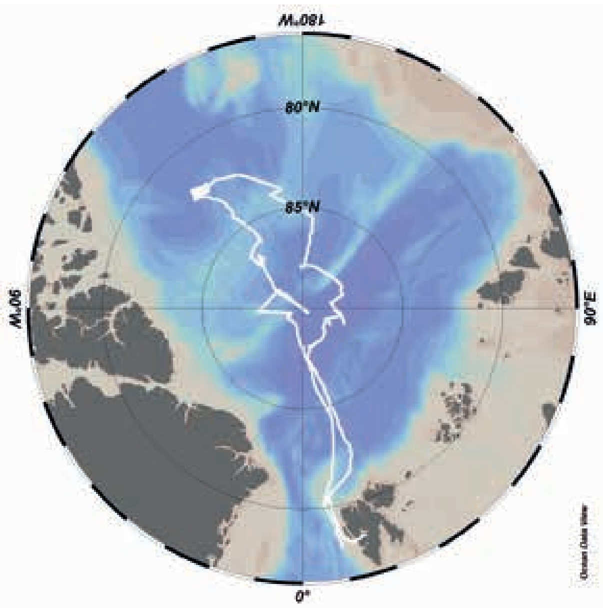


Figure 64: Track of the Icebreaker Oden during AO 2016. Courtesy: Hans-Martin Heyn, NTNU.

The icebreaker Oden departed from Longyearbyen, Svalbard, on the 8th of August to meet up with the Canadian icebreaker Louis S. St-Laurent and subsequently launch the expedition. During the six-week expedition, the vessels operated in the Amundsen Basin and in areas around the underwater mountain ranges Lomonosov Ridge and Alpha Ridge.

The objective of the Canadian research was to collect data in support of Canada's extended continental shelf sub-mission to the Commission on the Limits of the Continental Shelf, prepared in accordance with the United Nations Convention on the Law of the Sea (UNCLOS). This included mapping of the seafloor using seismic surveys, dredging, scanning by the multibeam echosounder, taking sediment core samples, and more. The work package of the NTNU PhD candidates encompassed *Ice Management* and in particular concerned ice surveillance techniques.

***Figure 65:** Icebreaker Louis S. St-Laurent (top) and icebreaker Oden. Photos: Runa A. Skarbø and Lars Lehnert (2016).*

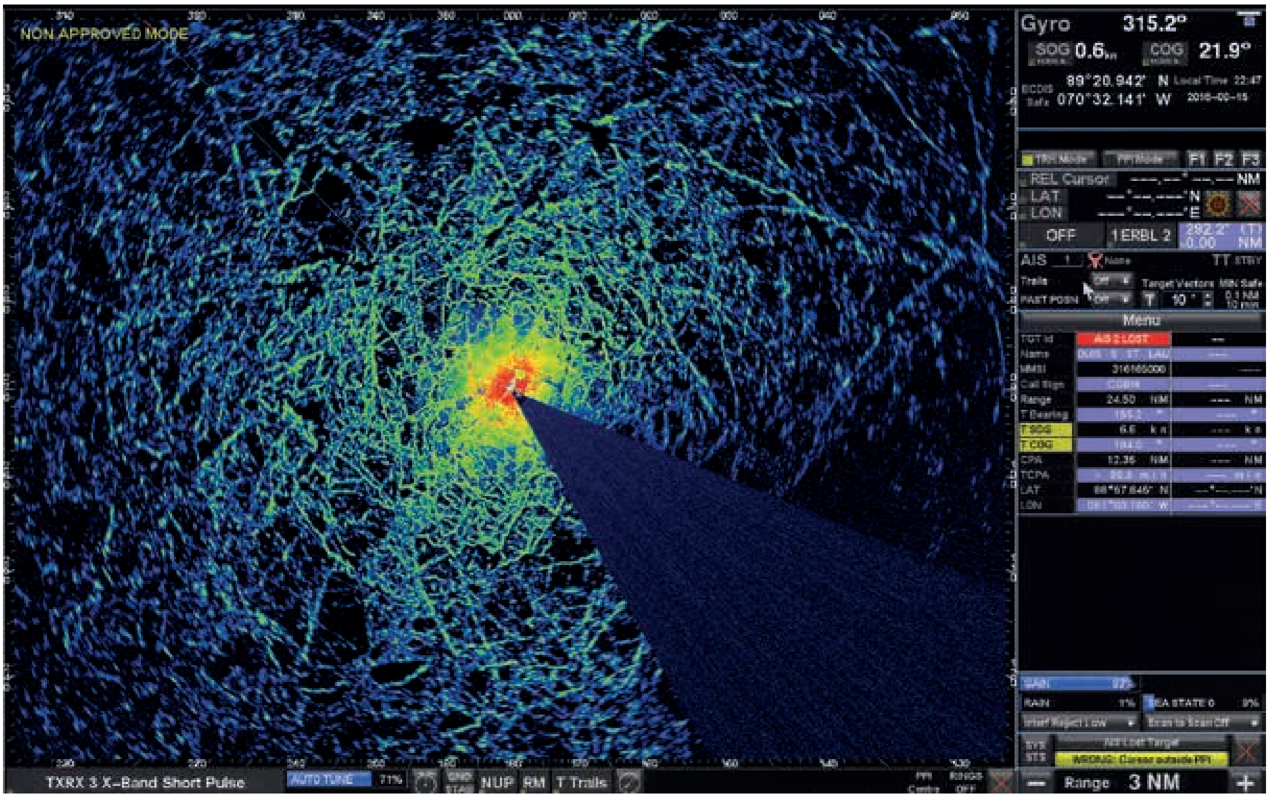


Figure 66: *Example of a radar screenshot in an ice management operation. Courtesy: Runa A. Skarbø, NTNU.*

Screenshots of the radar operator station were collected at selected locations when the vessel was stationary or drifting for more than four hours. A sequence of such radar screenshots with a resolution of 1920x1200 pixels, typically sampled at 1 Hz, combined with ship position reference and gyrocompass measurements can be fused with a computer vision algorithm to estimate accurately the sea-ice drift pattern in a range of 0.5 to 6 nautical miles around the vessel. This function, previously only achieved by manually deploying GPS trackers onto the sea-ice,

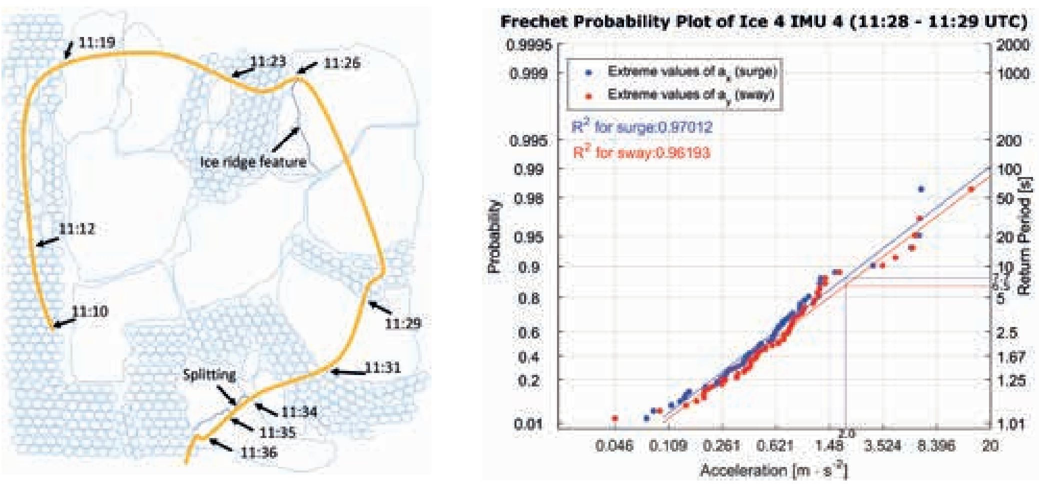


Figure 67: *Example track of the Icebreaker Oden through various ice regimes, reconstructed from the camera images, and the corresponding extreme load distribution fit for a part of the track. Courtesy: Hans-Martin Heyn, NTNU.*

is very important for safe and efficient ice management operations where understanding ice drift and especially changes in ice drift is a critical monitoring parameter.

Four inertial measurement units (IMUs) were also mounted on different locations in the vessel to monitor the ice-induced accelerations of the icebreaker hull during its contact with the ice during stationkeeping operation and transit through the sea-ice. The conjecture here is that the IMUs will contain in its acceleration measurement an information of the ice loads acting on the ship hull similar to what one could obtain from strain gauges. The IMU motion data were also supported by a system of 11 camera lenses that continuously monitored the ice conditions and icebreaking processes 360 degrees around and especially ahead of the vessel.

Our research at NTNU AMOS attempts to use the IMUs, cameras, and radar data for the online tracking and short-term prediction of the extreme ice loads acting on the vessel, estimation of local ice drift velocity and direction relative to the vessel, and real-time estimation of global ice loads on the vessel. In addition to functioning as an important image documentation system for validation purposes, the camera images are further used to estimate the local ice concentration and floe size distribution and possibly identify ice features such as ridges and melt ponds.

On the 22nd of August, our researchers arrived at the North Pole, where an ice station was set up and a barbeque dinner was organized.

Expeditions such as this are invaluable for supporting the theoretic research and development of numerical models and algorithms at NTNU AMOS and CRI SAMCoT with observation data to understand the involved physical processes from real field and validation data on which to test the algorithms. We would like to thank the Swedish Polar Research Secretariat for inviting our PhD candidates on board and allowing them to collect the data we wanted.

Media coverage:

- NRK: Reiser til Nordpolen for å forske på isen, 7 August 2016
- Sysla Maritime: Drar til Nordpolen for å finne ut hvordan skip kan takle isen, 1 August 2016
- Gemini.no: Three Arctic researchers at North Pole, 25 August 2016
- NTNU TechZone: Follow me to the North Pole, 18 September 2016

Figure 68: The NTNU PhD candidates on AO2016. From left to right: Jon Bjørnø, Runa Skarbø, and Hans-Martin Heyn.

Field test campaign: Coordinated operation of unmanned underwater, surface and aerial vehicles enabled by broadband communication network

Supervisor: Prof. Tor Arne Johansen
PhD candidates: A. Zolich, S. M. Albrektsen, K. Cisek, T. O. Fossum, P. Norgren

Conventional ships can multiply their capacity by hosting and controlling a fleet of smaller autonomous unmanned vehicles in the air, on the surface and under water. Such capacities enable extended observations of objects and features of interest from different positions and with different sensors but possibly at the same location and at the same time. The complementary features of the aerial, surface and underwater vehicles with respect to mobility, viewpoint, communication and sensor payload require careful coordination and optimization of the mission.

The backbone of such operations is communication networks enabling the vehicles and control centres (on ship or shore) to share information and commands. Moreover, software and interfaces are required to achieve situational awareness and enable command and control to operate and coordinate the vehicles from a joint operations centre. For example, the aerial vehicles can provide real-time video and sensor feeds from the air, which can be used to direct and optimize the operation of the surface and underwater vehicles. The surface vehicles can utilize both hydro-acoustic communication with the underwater vehicles and radio communication with the aerial vehicles. Both surface and aerial vehicles can function as communication relay nodes, which can greatly extend the datalink capacity between the control centres and the vehicles.

The operating concept was successfully demonstrated and tested in a field experiment using real-time broad-

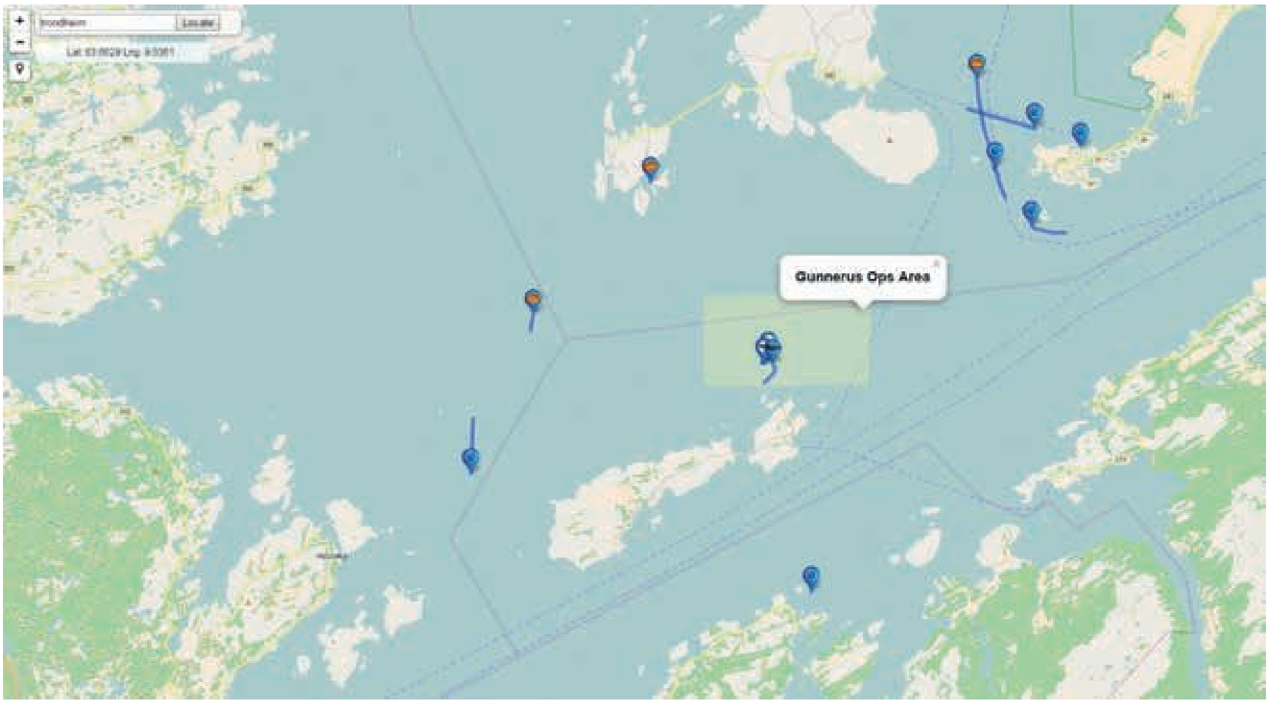


Figure 69: Real-time situational picture from the Ripples server showing all vehicles under command in the operating area, as well as other traffic monitored by AIS (sea) and ADS-B (air). Interoperability and a common picture are enabled by the LSTS software toolchain (developed by the University of Porto).

band networking between several manned and unmanned vehicles in different scenarios. The communication and Maritime Broadband Radio (MBR) networking technology was provided by Kongsberg Seatex and Radionor Communications, and field tests with aerial, surface and underwater vehicles and additional networking hardware and software from NTNU, FFI, Maritime Robotics, and the University of Porto were performed near Agdenes in May 2016.

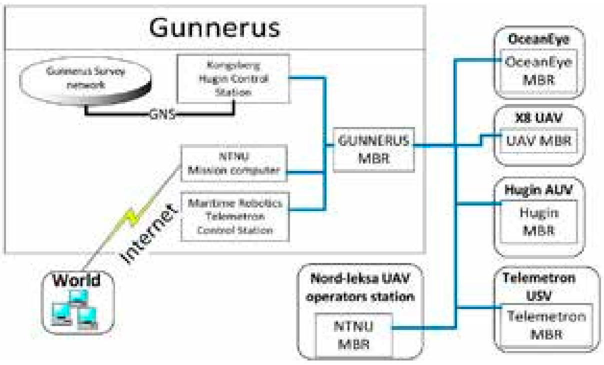


Figure 70: *The diagram shows the MBR radio communication network configuration, operating out of RV Gunnerus as the main control centre.*

To demonstrate the capabilities of the proposed system, a scenario with seabed mapping and object recognition was defined. The experiment made it apparent that these networks have the potential for significant cost savings for data collection in marine research and management through reducing ship time. Communication performance and robustness have shown to be excellent in a wide range of challenging conditions, including low antenna elevation, long range, highly dynamic manoeuvring and close to no line of sight situations.

Media coverage and selected publication:
Article in the Norwegian engineering magazine Teknisk Ukeblad describing the experiments and the overall visions behind the research:
Teknisk Ukeblad: Her er Norge verdensledende. Nå skal vi gjøre det til en milliardindustri, 4 June 2016

Ludvigsen, Martin; Dias, Paulo Sousa; ferreira, sergio; Fossum, Trygve Olav; Hovstein, Vegard Evjen; Johansen, Tor Arne; Krogstad, Thomas Røbekk; Midtgaard, Øivind; Norgren, Petter; Sousa, João Borges de; Sture, Øyvind; Vågsholm, E; Zolich, Artur Piotr. Autonomous Network of Heterogeneous Vehicles for Marine Research and Management. OCEANS; 2016-09-19 - 2016-09-23

Figure 71: *The picture shows FFI's HUGIN AUV at the surface in front of Maritime Robotics' Telemetron ASV. They are communicating via the MBR network. Photo: Maritime Robotics.*

NTNU AMOS DP research cruise 2016

Supervisors: Prof. Roger Skjetne, Dr Morten Breivik
PhD candidates: Astrid H. Brodtkorb, Svenn A. T. Værnø, Mikkel E. N. Sørensen
Postdoc: Øivind K. Kjerstad
MSc candidate: Alexander Mykland

The NTNU AMOS DP Research Cruise 2016 (ADPRC'16) was organized for weeks 42 and 46, with the objective to test DP- and autopilot-related control methods in full-scale operation on R/V Gunnerus. Three PhD candidates and one postdoc were testing results from their scientific work at NTNU AMOS. The control methods are related to safer and more environmentally robust control and observer algorithms under transient conditions. Such transients, which typically have a detrimental effect on DP performance in conventional systems, can originate from operations in harsh environments – such as sudden large wave trains or drifting sea ice – or abrupt operational changes such as touchdown or release of legs for a DP-controlled jackup rig. During two isolated weeks of testing, many different control algorithms were tested, resulting in both successful and non-successful outcomes. Scientific data were acquired, as well as important learning experiences for our researchers.

In spring 2016, we took the initiative to a discussion with Kongsberg Maritime (KM), supplier of the DP control system onboard R/V Gunnerus, to determine if it was possible for NTNU AMOS researchers, through a customized test module in the Gunnerus DP software, to perform experimental testing of our experimental control algorithms. Principal engineer Vincenzo Calabro, PhD, at KM quickly provided a technical solution, and then, it was simply up to the "bosses" to decide if this should be done and if a DP research campaign should be scheduled. It was found to be beneficial for both Kongsberg Maritime, as a collaborator at NTNU AMOS, and our researchers to use this solution; then, the real planning and preparations for the ADPRC'16 test campaign were started.

Soon after summer, from Aug. 8th-10th, our researchers travelled to Kongsberg to attend a 3-day DP coding workshop, with the objective of learning how to code real DP

Figure 72: *NTNU's research vessel Gunnerus.*

software. These researchers were the PhD candidates Astrid H. Brodtkorb and Svenn A. T. Værnø from the Dept. of Marine Technology and Mikkel E. N. Sørensen from Engineering Cybernetics and the postdoc Øivind K. Kjerstad from University Centre at Svalbard, who were accompanied by Prof. Roger Skjetne. After the workshop, a selection of algorithms was made, and implementation and testing of the code were conducted throughout September and into October. On Oct. 10th, the code was frozen to undergo code review and software build.

During Week 42, Oct. 17-21, the first week of testing was conducted. The first two days were scheduled for system preparations and testing in the fjord outside Trondheim. Then, aiming for more waves further out in the fjord, we sailed to Brekstad from Wednesday-Friday. Unfortunately, the waves that we were searching for were not to be found due to the record-breaking nice October weather. Instead, we found some areas of high rotational currents and vortices by the Smellingen island close to Brekstad, where several tests were performed.

During Week 46, Nov. 14-18, we repeated the testing after a 3-week period of learning from our experiences, replanning, and implementation of new and improved control algorithms. We again went to Brekstad from Wednesday-Friday after two days of preparatory testing outside Trondheim, and once again, we found no waves all the way out to Frohavet, where the ocean opens up towards the Norwegian Sea.

Figure 74: *Svenn Are T. Værnø and Astrid H. Brodtkorb discussing technical DP details, with MSc student Joachim Spange keenly watching them. Photo: Roger Skjetne, NTNU.*

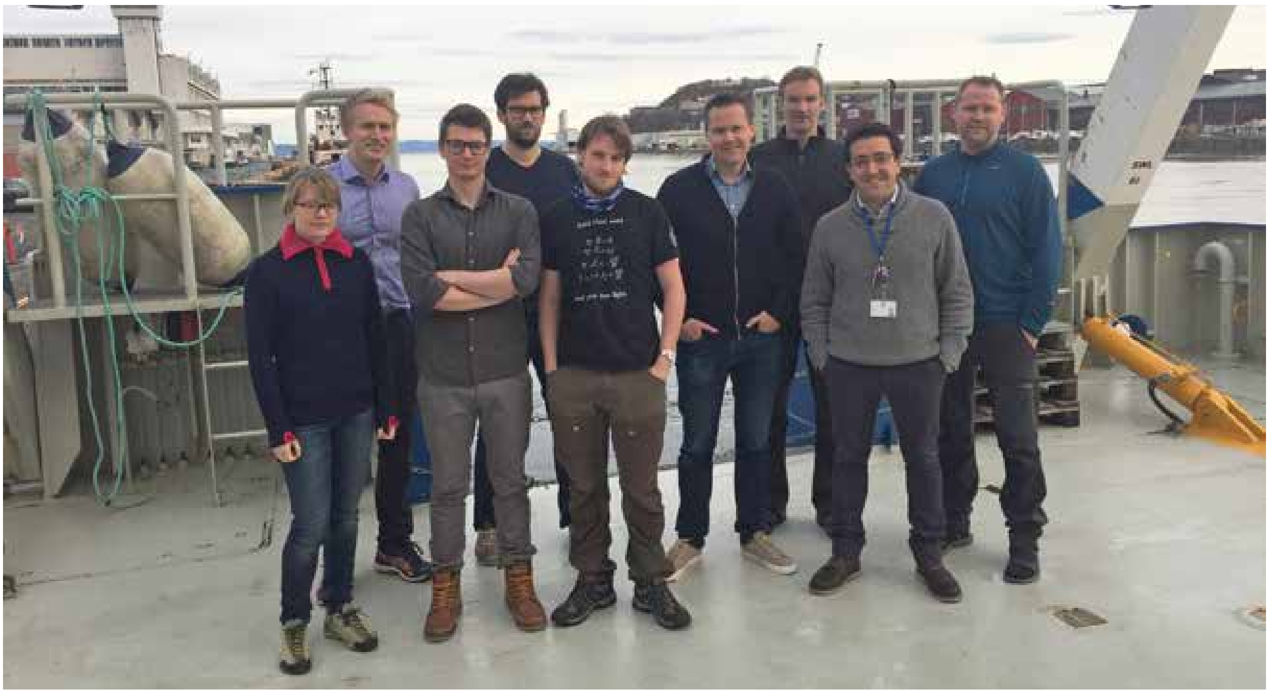


Figure 73: *NTNU AMOS researchers and Kongsberg engineers on board R/V Gunnerus. From left to right: PhD candidate Astrid H. Brodtkorb and Svenn A. T. Værnø, postdoc Øivind K. Kjerstad, MSc student Alexander Mykland, PhD candidate Mikkel E. N. Sørensen, Dept. head Morten Breivik, KM principal eng. Rune Skullestad, KM principal eng. Vincenzo Calabro, and Prof. Roger Skjetne. Photo: Captain Arve Knudsen.*

Various control and observer algorithms were tested. Among the DP control laws, we tested algorithms called adaptive backstepping nonlinear update, adaptive backstepping saturated virtual controls, pseudo-derivative feedback (PDF) DP control, proportional derivative bias rejection control, PDF+AFF (acceleration feed forward), etc. For the DP observers, a nonlinear passive observer, a signal-based observer, and a hybrid version of these observers were within the scope of study. In addition, we tested autopilots, typically while in transit to and from Brekstad. These were based on PDF, adaptive back-stepping, and model-reference adaptive control methods.

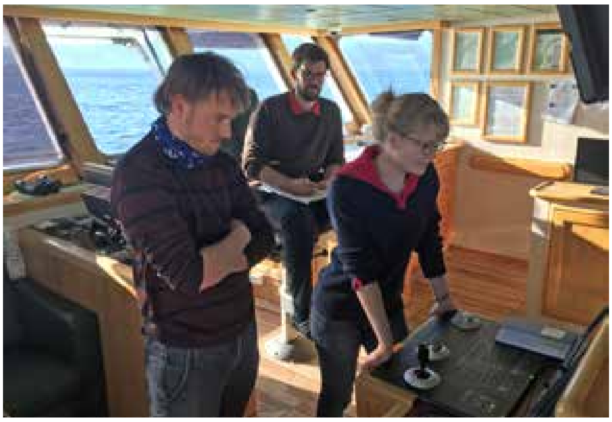


Figure 75: Mikkel E. N. Sørensen and Astrid H. Brodtkorb performing their tests from the DP operator station on the Gunnerus bridge while Alexander Mykland records actions and observations comfortably from the DP chair. Photo: Roger Skjetne, NTNU.

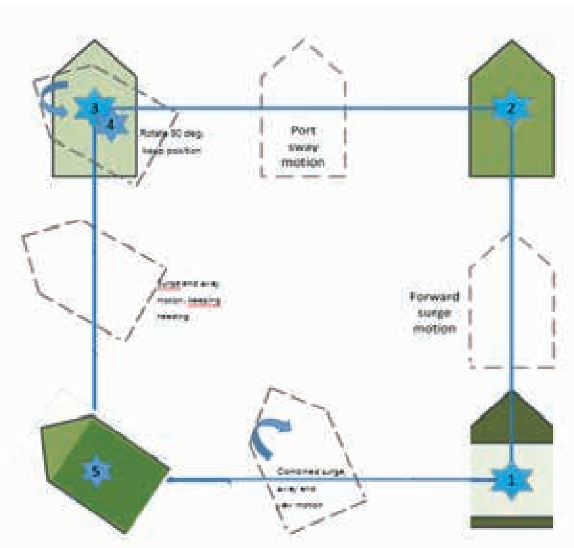


Figure 76: The 4-corner DP test conducted in most experiments with 40 m displacements along the sides.

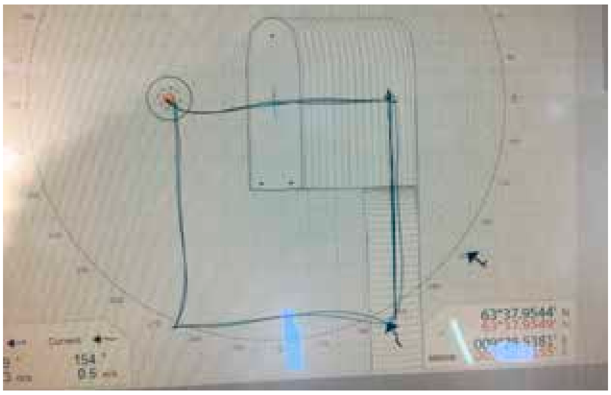


Figure 77: Trace of the successful DP footprint after one run of Øivind Kjerstad's testing of the PDF DP control law in a 4-corner test. Photo: Roger Skjetne, NTNU.

A few MSc candidates were also invited to join and learn from the testing. Among them, MSc. cand. Alexander Mykland joined the cruise for the full two weeks and took upon himself to be the main person responsible for the log-book, therein recording all actions and observations for the testing on the bridge.

We would like to thank Kongsberg Maritime for preparing the test interface and providing the necessary resources from their side, which made this expedition possible.

Figure 78: KM principal engineer Vincenzo Calabro explaining the DP operator station to eager MSc students. From left: Joachim Spange, Vincenzo Calabro, Alexander Mykland, and Silje A. Johannessen. Photo: Roger Skjetne, NTNU.

Media coverage:

- Gemini.no: Tester ut elektronisk anker på eget forskningsfartøy, 28 November 2016
- Kongsberg: University Students and Researchers Test Own Control Algorithms on Industrial DP System Platform, 25 November 2016

HONOURS AND AWARDS

Honours

NTNU AMOS keyperson Prof. Kristin Y. Pettersen is the first Norwegian woman to become an IEEE fellow

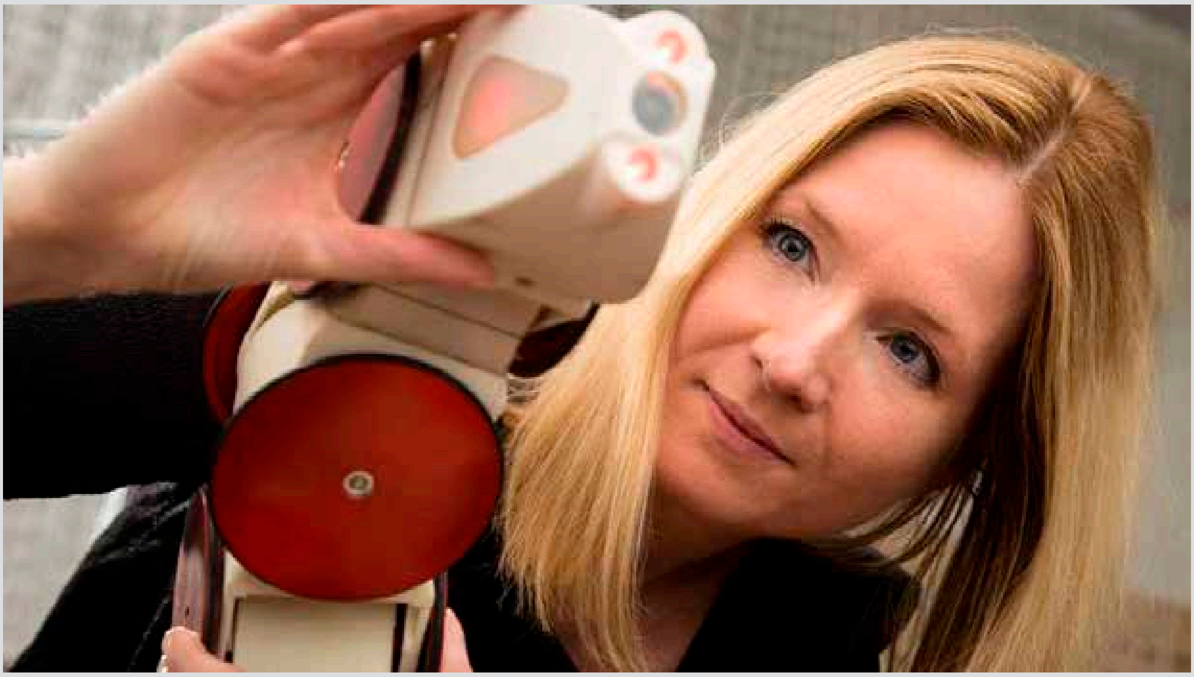


Figure 79: *NTNU AMOS keyperson Prof. Kristin Y. Pettersen. Photo: Kai T. Dragland, NTNU.*

Media coverage:
- Adresseavisen: Ærestittel for slangerobot-forsker ved NTNU, 25 November 2016
- Universitetsavisa: Hun er første norske kvinne som blir IEEE fellow, 23 November 2016

NTNU AMOS advisor Prof. Moan graduates his 75th PhD candidate
NTNU AMOS advisor Prof. Torgeir Moan graduated his 75th PhD candidate, Lin Li, on 31 May 2016 at the Marine Technology Centre in Trondheim. Dr Li's thesis is entitled "Dynamic Analysis of the Installation of Monopiles for Offshore Wind Turbines".

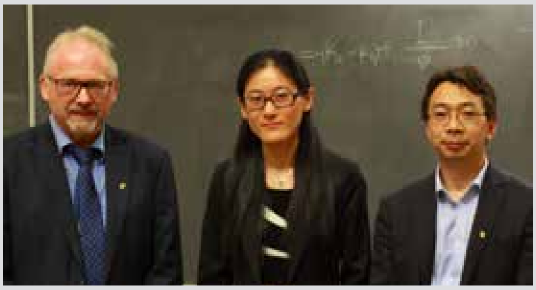


Figure 80: *From the left: Prof. Torgeir Moan, Dr Lin Li and Dr Li's co-supervisor Prof. Zhen Gao. Photo: Jon Are Nilsen, NTNU.*

Prof. Odd M. Faltinsen held the **24th Wallace Lecture in Ocean Sciences and Engineering** about sloshing at the Massachusetts Institute of Technology (MIT), Department of Mechanical Engineering, on 1 April 2016.

PhD graduate Arnt G. Fredriksen named Europe's most talented engineer
Dr Arnt G. Fredriksen was named the most talented engineer in the yearly engineering competition organized by the European federation of Engineering Consultancy Associations (EFCA).

Find more information about the honour in Teknisk Ukeblad: Norsk ingeniør hedret i internasjonal konkurranse, 3 June 2016

Figure 81: *Dr Arnt G. Fredriksen at the EFCA Conference 2016. Photo: Liv Kari Hanseteen.*

Awards

Prof. Asgeir J. Sørensen receives the SOBENA International Award

Figure 82: *Prof. Sørensen's SOBENA International Award 2016.*

Like Prof. Torgeir Moan and Prof. Odd M. Faltinsen before him, Prof. Asgeir J. Sørensen received the SOBENA International Award in recognition for his outstanding contribution to the progress of naval architecture and ocean engineering. Prof. Sørensen was handed the award at the biannual conference of SOBENA, the Brazilian Society of Naval Architecture, Marine and Offshore Engineering, on 9 November 2016 in Rio de Janeiro. Find more information about the honour on NTNU AMOS's webpage

Prof. Torgeir Moan is awarded the Davidson Medal

Figure 83: *From the left: SNAME Vice-president Prof. Apostolos Papanikolaou, Prof. Torgeir Moan and SNAME president Mr. Joseph Comer. Photo: Sergio Pantoja/SNAME.*

The Society of Naval Architects and Marine Engineers (USA) awarded the Davidson Medal to NTNU AMOS adviser Prof. Torgeir Moan for "Outstanding Scientific Accomplishment in Ship Research." He was handed the medal during an award ceremony at the SNAME Annual Meeting in Seattle on 3 November 2016.

Prof. Martin Ludvigsen receives the Kom-Award
Prof. Martin Ludvigsen received the Kom-award and the title "Best Communicator of the Year" from the Faculty of Engineering Science and Technology at the annual party of the Faculty of Engineering Science and Technology 26 October 2016 at Banksalen in Trondheim for doing an excellent job communicating his research to a wider audience.

Figure 84: *Prof. Martin Ludvigsen with the Kom-Award. Photo: NTNU.*

NTNU AMOS researchers receive the NOWITECH Innovation Award 2016

Figure 85: *From the left: NTNU AMOS PhD candidate Thomas Sauder, NTNU AMOS Adj. Ass. Prof. Erin E. Bachynski, MARINTEK researcher Maxime Thys, PhD candidate Valentin Chabaud from NTNU's Dept. of Marine Technology, committee chair Oddbjørn Malmo from Kongsberg Maritime and John Olav Tande from SINTEF Energy Research. Photo: Hans Christian Bolstad, SINTEF.*

Find more information about the honour in the blog from SINTEF Energy: NOWITECH Innovation Award 2016, 16 June 2016

NTNU AMOS spin-off company Eelume receives the GCE Subsea Upcoming Company of the Year Award 2016

Figure 86: *From the left: Hars Erik Berge (UTF), Trond Lægreid (Sparebanken Vest), Prof. Kristin Y. Pettersen (NTNU AMOS and Eelume), Asle J. Hovda (Eelume) and Owe Hagesæther (GCE Subsea). Photo: Tove Lise Mossestad.*

NTNU AMOS spin-off company Eelume received this year's "Subsea Upcoming Company Award" from GCE Subsea for their disruptive technology for inspection, maintenance and repair operations for subsea-related industries. The award was given to Eelume as the best of four strong candidates and was presented to them at the Underwater Technology Conference 2016 in Bergen 14 June 2016.

Find more information at GCE Subsea: Simplified subsea intervention with an electric eel, 15 June 2016

Best paper award
Prof. Trygve Kristiansen received the award for the best paper of the offshore technology symposium at the OMAE-conference 2015. The award was presented to him at OMAE 2016 in Busan, South-Korea, 19-24 June 2016.

Kristiansen, Trygve; Ommani, Babak; Berget, Kjetil; Baarholm, Rolf Jarle. An experimental and numerical investigation of a box-shaped object in moonpool; a three-dimensional study. 34th International Conference on Ocean, Offshore and Arctic Engineering (OMAE 2015); 2015-05-31 - 2015-06-05

NTNU AMOS spin-off company BluEye wins innovation award

Figure 87: *NTNU AMOS spin-off company BluEye wins the innovation award "Trøndelagsmøtets gründerpris" among 9 nominated companies. From the left: Erik Dyrkooren (BlueEye), the Norwegian Minister of Foreign Affairs Børge Brende, Christine Spliten (BluEye) and Eli Arnstad (director in Spare-Bank1 SMN). Photo: Trønder-Avisa.*

Find more information in Trønder-Avisa: Dyp idé vant gjev innovasjonspris, 14 January 2016

Moan-Faltinsen Best Paper Awards

This year's Moan-Faltinsen Best Paper Awards were presented at MARINTEK's and NTNU's Christmas lunch on 21 December 2016 at the Marine Technology Centre.

Peng Li was the recipient of the award within marine hydrodynamics for his paper "Nonlinear vertical accelerations of a floating torus in regular waves", published in the *Journal of Fluids and Structures* (2016, 66: 589-608) and co-authored by Prof. Odd M. Faltinsen and Adj. Prof. Claudio Lugni.

Ming Song received the award within marine structures for her paper "A comparative analysis of the fluid-structure interaction method and the constant added mass method for ice-structure collisions", published in *Marine Structures* (2016, 49: 58-75) and co-authored by Dr Ekaterina Kim, Prof. Jørgen Amdahl, Jun Ma and Yi Huang.

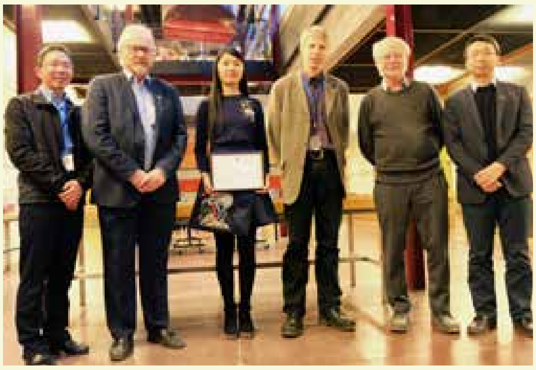
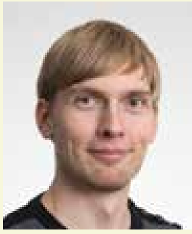


Figure 88: *Left photo from the left: Naiquan Ye, Prof. Torgeir Moan, Ming Song, Prof. Sverre Steen, Prof. Odd M. Faltinsen and Prof. Zhen Gao. Right photo from the left: Peng Li and Prof. Odd M. Faltinsen. Photos: Kun Xu, NTNU.*

For more information about the achievements listed here as well as to retrieve more NTNU AMOS news, visit:

www.ntnu.edu/amos/newsandevents

INTERVIEWS WITH PHD CANDIDATES



Jakob Mahler Hansen

PhD candidate at NTNU AMOS

Age: 28
PhD topic: Nonlinear observers for loosely- and tightly-coupled INS/RTK GNSS integration

Time left in the program: 2 months
Supervisor: Prof. Thor I. Fossen
Co-supervisors: Prof. Tor Arne Johansen, Adj. Ass. Prof. Nadezda Sokolova
Where are you from?: Holbæk, Denmark

Why did you choose to become a PhD candidate?
It seemed like a natural development after my Bachelor and Master studies. I felt the university still had a lot left to offer. I wanted to explore the scientific world a bit more before working in the industry, so I applied for a position at AMOS when my former supervisor encouraged me to.

How is it to be a PhD candidate at NTNU AMOS?
It's optimal: you have a lot of colleagues at the same age, so you get a large multi-national network. You have extremely skilled professors who help you, and you get into contact with the industry, which ensures your research is relevant. The professors are the smartest people I know in their field, and it's inspiring to work with them. I am proud to have them on my resume.

What is the best thing about being a PhD candidate?
The colleagues, the other PhD candidates. They are a great help when being confronted with problems, reassuring you of your progress and being supportive in general. Also, exchanging code and knowledge in general is very valuable. It can be competitive in the scientific community, but it shouldn't be – and here, it is not.

What is the worst thing about being a PhD candidate?
Because of the excellent work carried out at AMOS, I strive to excel. That can be stressful at times. Also, comparing oneself to other people – number of publications, work hours – can take a toll on you.

Is it worth it?
At this point, definitely. It is quite a quality stamp to have a PhD degree from AMOS.

What is your primary research field at NTNU AMOS?
Precise navigation of vehicles using inertial sensors and GNSS receivers. I am focusing on unmanned aerial vehicles because they have fast dynamics and can be seen as worst-case scenarios, although the research can be used for many vehicle types.

Have you had any research stays abroad during your time at NTNU AMOS?
Yes. I went to the University of Calgary in Canada for 5 months. I studied inertial navigation and GNSS disturbances there. It was a great stay. It was good for me to see how they work at other universities and get confirmation that AMOS is world-leading in its field.

How do you like living in Trondheim?
It's nice. Norway is on my short list of countries I can see myself living in for a longer period of time. I like Trondheim. It's a nice city: it's not too small but still cozy. Even though it can get a little empty during summer vacation because it is a student city.

What are your plans for the future?
I am moving back to Denmark to be closer to family and friends. I would like to stay in a role in the industry where I can still do research, and I would like to maintain my university contacts. Hopefully, in the future, I can combine working in the industry with publishing scientific results.

Siri Holthe Mathisen

PhD candidate at NTNU AMOS

Age: 26
PhD topic: Embedded optimization for autonomous unmanned aerial vehicle mission planning and guidance

Time left in the program: ca. 1.5 years
Supervisor: Prof. Tor Arne Johansen
Co-supervisor: Prof. Thor I. Fossen
Where are you from?: Trondheim, Norway

Why did you choose to become a PhD candidate?
It's a chance that I couldn't let pass. The opportunity was there. I have always played with the thought about doing something related to research, but it wasn't until a position at AMOS opened that I decided to do something about it.

How is it to be a PhD candidate at NTNU AMOS?
It is great. It is good to be a PhD candidate because it gives me an opportunity to grow professionally and personally, and you have a great social network which also helps you. This network is one of the things that is really great about NTNU AMOS as well, there is always someone to talk with, both about work and other things.

What is the best thing about being a PhD candidate?
If you are able to work in a structured manner and still get your work done, you have great freedom. It is essential that one can turn off the stress button, though.

What is the worst thing about being a PhD candidate?
It can be stressful, both in down periods and in intense periods: in down periods, you can get stressed because you don't get anything done.

Is it worth it?
Yes, because it gives me the opportunity to grow. Especially when I compare my everyday life with those who have the same education but work in the industry: I can take courses and educate myself on many different topics, while they work mainly with one thing.

What is your primary research field at NTNU AMOS?
I am working with model predictive control of UAVs to perform a specific landing method on a small landing platform. I also touch upon precision drop from the UAV. I hope to combine those two fields.

Have you had any research stays abroad during your time at NTNU AMOS?
No, but I'm still hoping for it! I have some ideas.

How would you describe your experience as a candidate at Researcher Grand Prix this year?
It was a good experience, and I learned a lot. My main motivation was to push myself and push my limits. I recommend it for everyone who would like to challenge themselves and learn how to present their research in a popular manner. Opportunities like that don't come very often!

What are your plans for the future?
I plan to finish in time. Afterwards, I imagine working in both academia and industry would be fun, but I really don't know yet.

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
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. Hassani, Vahid	NTNU, Dept. Marine Technology	Marine control	VH
Adj. prof. Johansson, Karl H.	NTNU, Dept. Engineering Cybernetics	Networked and distributed control and estimation; cyber-physical and cyber-secure control systems; hybrid and embedded systems; applications in transportation, energy, and automation networks	KHJ
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/researchers

Name	Institution	Main field of research	Acronym
Dr Amelin, Konstantin	NTNU, Dept. Engineering Cybernetics	Multi-agent AUV-systemer	KA
Dr Cheng, Zhengshun	NTNU, CeSOS	Characteristic environmental loads and load effects for ULS and ALS design check of floating bridges; offshore wind turbines	ZC
Dr Cristofaro, Andrea	NTNU, Dept. Engineering Cybernetics	Optimization	AC
Dr Haring, Mark	NTNU, Dept. Engineering Cybernetics	Nonlinear filtering and observer theory	MH
Dr Kelasidi, Eleni	NTNU, Dept. Engineering Cybernetics	Resident robot manipulators for subsea IMR	ElK
Dr Kim, Ekaterina	NTNU, Dept. Marine Technology	Understanding rare, extreme ice-structure collisions	EK
Dr Kufoalor, Giorgio Kwame	NTNU, Dept. Engineering Cybernetics	To develop an overall system architecture of a future navigation and control system with sensor fusion and collision avoidance (COLAV)	GKK
Dr Liljebäck, Pål	NTNU, Dept. Engineering Cybernetics	Snake robots	PL
Dr Ommani, Babak	MARINTEK	Numerical modelling for nonlinear stochastic processes	BO
Dr Raskehi Nejad, Amir	NTNU, CeSOS	Dynamic analysis, design, condition monitoring and fault detection of drivetrains in floating wind turbines	ARN
Dr Rotondo, Damiano	NTNU, Dept. Engineering Cybernetics	Gain-scheduled control systems, fault detection and isolation (FDI) and fault tolerant control (FTC) of dynamic systems	DR
Dr Sha, Yanyan	NTNU, Dept. Marine Technology	Ship collision analysis of floating bridges in ferry-free-E39 project	YS
Dr Sørensen, Kim Lynge	NTNU, Dept. Engineering Cybernetics	Development of icing protection solution for small unmanned aircraft	KLS
Prof. Tymokha, Oleksandr	NTNU, Dept. Marine Technology	Mathematical aspects of hydromechanics with emphasis on free-surface problems (sloshing)	OT

Affiliated scientists

Name	Institution	Main field of research	Acronym
Ass. prof. Alfredsen, Jo Arve	NTNU, Dept. Engineering Cybernetics	Automation in fisheries and aquaculture	JAA
Ass. Prof. Bachynski, Erin E.	NTNU, Dept. Marine Technology	Wind energy/offshore renewable energy systems	ErB
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	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
Prof. Kristiansen, Trygve	NTNU, Dept. Marine Technology	Marine hydrodynamics	TK
Prof. Ludvigsen, Martin	NTNU, Dept. Marine Technology	Underwater technology and operations	ML
Prof. Molinas, Marta	NTNU, Dept. Engineering Cybernetics	Smart grid: modeling and stability analysis of power electronics systems	MM
Prof. Schjølberg, Ingrid	NTNU, Dept. Marine Technology	Underwater robotics	IS
Prof. Skjetne, Roger	NTNU, Dept. Marine Technology	Marine control systems	RS
Ass. prof. Stahl, Annette	NTNU, Dept. Engineering Cybernetics	Robotic vision	AS
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
De Figueiredo Vieira, Ricardo	Inst. Superior de Engenharia de Lisboa	Analyses of wind turbine offshore structures	RFV
Macias, Alberto Ramirez	Universidad Pontifica Bolivariana	ROV design, modelling, hydrodynamics, control	ARM
Prof. Prpic-Orsic, Jasna	Univ. of Rijeka, Croatia	CO_2 emission from ships in waves	JP
Prof. Teel, Andrew R.	Univ. of California, Santa Barbara, USA	Hybrid dynamical systems	AT
Dr Wang, Jingbo	National Science Foundation of China/ CNR-INSEAN	Water impact	JW

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

Name	Period (yyyymmdd)	Supervisor	Topic
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
Sørum, Stian Høegh	20160901-20200115	JAM	How to design and operate sustainable and autonomous systems for offshore renewable energy in shallow-to-deep waters
Vilsen, Stefan A.	20140201-20180131	AJS/HG	Hybrid model testing of marine systems
Værnø, Svenn Are T.	20140101-20161231	RS	Topics in motion control of offshore vessels
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)	Supervisor	Topic
Aamot, 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
Andrade, Fabio	20160701-20190701	RSt	Sea ice drift tracking using real time UAV path planning for maritime situational awareness
Bjørne, Elias	20150815-20180814	TAJ	Nonlinear observer theory for simultaneous localization and mapping
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

Name	Period (yyyymmdd)	Supervisor	Topic
Dahl, Andreas Reason	20130819-20160818	RS	Nonlinear and fault-tolerant control of electric power production in Arctic DP vessels
Eriksen, Bjørn-Olav H.	20150803-20180802	MBR	Collision avoidance for autonomous surface vehicles
Flåten, Andreas L.	20150803-20180802	EB	Multisensor tracking for collision avoidance
Fossum, Trygve Olav	20160501-20181130	ML	Artificial intelligence for AUVs
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
Gunnu, Giriraja Sekhar	2016xxx-20170601	TM	Safety and efficiency enhancement of anchor handling operations with particular emphasis on the stability of anchor handling vessels
Hann, Richard	20160615-20190614	TAJ	Icing and anti-icing of UAVs
Hansen, Jakob Mahler	20130801-20160731	TIF	Nonlinear observers for tight integration of IMU and GNSS pseudo-range and carrier-phase-ambiguity resolution
Haring, Mark	20110921-20160623	TAJ	Extremum-seeking control, convergence improvements and asymptotic stability
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
Hovenburg, Anthony	20160101-20181231	RSt	Modular design framework for RPAS operating in marine environments
Jørgensen, Ulrik	20100830-20140331	RS	Autonomous underwater ice observation system
Kjerstad, Øivind K.	20100801-20141231	RS	Dynamic positioning of marine vessels in ice
Leonardi, Marco	20160815-20190814	AS	Visual odometry and servoing for 3D reconstruction
Li, Lin	20110810-20160531	TM/ZG	Numerical simulations of offshore wind turbine installation
Li, Qinyuan	20110710-20160709	TM	Long-term extreme response prediction for offshore wind turbines
Luan, Chenyu	2010xxxx-20170601	TM	Efficient stochastic dynamic response analysis for design of offshore wind turbines
Mathisen, Siri Holthe	20140818-20170817	TAJ	Embedded optimization for autonomous unmanned aerial vehicle mission planning and guidance
Miyazaki, Michel Rejani	20130503-20170502	AJS	Control of hybrid power plants
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
Ren, Zhengru	20160101-20181231	RS	Monitoring and control of crane operations for fixed and floating offshore wind turbines
Rodin, Christopher Dahlin	201508xx- 201807xx	TAJ	Intelligent data acquisition in maritime UAS
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

Name	Period (yyyymmdd)	Supervisor	Topic
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
Souza, Carlos E. Silva de	20160812-20200811	ErB	Structural modeling and optimization of floating wind turbines
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
Ueland, Einar S.	20160815-20190814	RS	Study of fundamental constraints in the hbrid test loop, and optimal control and estimation strategies for actuation of effort on the physical system
Wan, Ling	20140101-20160630	TM	Experimental and numerical study of a combined offshore wind and wave energy converter concept
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
Wu, Xiaopeng	20100810-20150615	TM	Numerical analysis of anchor handling and fish trawling operations in a safety perspective
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 prof./Ass. prof.	Affiliated scientist	Scientific advisor	Postdoc/ affiliated postdoc	Visiting professor/ researcher	PhD	Assoc. PhD	Administrative staff *)	SUM
Norwegian	5	4	10	2	2	0	15	25	5	68
Other nationalities	1	5	4	0	12	7	16	28	1	74
SUM	6	9	14	2	14	7	31	53	6	142
Man-years	3.5	1.5	4.9	2.0	6.1	1.4	28.9	43.3	3.2	94.8

*) incl. technical staff

Destination of PhD candidates and postdoctoral researchers leaving NTNU AMOS (2013-2016), in per cent

	Industry	Research institute	Academia	Out of Norway
PhD candidates	52	3	45	20
Postdocs/ researchers	0	33	67	67

Total man-year efforts

Man-years	2016
Centre director	0.3
Co-director	0.2
Adm.personnel	1.7
Technical staff	1.0
Summary	3.2
Key professor	3.5
Adjunct prof/ass.prof	1.5
Affiliated prof/scientists	6.9
Postdocs	6.1
Visiting researchers	1.4
PhD candidates*)	72.2
Total research man-years	91.6
Total	**94.8**

*) 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		24 032
NTNU	1	30 857
Others	2	8 290
In-kind	3	25 970
Sum operating income		89 149
Operating costs		
Salary and social costs	4	48 363
Equipment investments		400
Procurement of R&D services		4 532
Other operating costs	5	5 551
In-kind	3	25 970
Sum operating costs		**84 816**
Year end allocation		**4 333**
Opening balance 20160101		3 374
Closing balance 20161231		7 707

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

Research and education

PhD courses in 2016

Code	Subject	Person in charge
30324 (DTU)	Advanced Topics in Diagnosis and Fault-tolerant Control	Mogens Blanke
AB334/AB834 (UNIS)	Light & Primary Production in the Arctic	Geir Johnsen
MR8300	Hydrodynamics for Marine Structures 1 (PhD course)	Marilena Greco
MR8306	Hydrodynamics for Marine Structures 2 (PhD course)	Trygve Kristiansen
MR8500	Advanced Topics in Marine Control Systems	Roger Skjetne and Andrew R. Teel
MR8501	Advanced Topics in Structural Modelling and Analysis	Jørgen Amdahl
MR8503	Stochastic Methods Applied in Nonlinear Analysis of Marine Structures	Zhen Gao
TK8102	Nonlinear State Estimation	Edmund F. Brekke
TK8109	Advanced Topics in Guidance and Navigation	Thor I. Fossen
TK8115	Numerical Optimal Control	Tor Arne Johansen

Master courses in 2016

Code	Subject	Involved NTNU AMOS person
AT334 (UNIS)	Arctic Marine Measurements Techniques, Operations and Transport	Martin Ludvigsen
BI3060	Methods in Marine Biology	Geir Johnsen
BI3061	Biological Oceanography	Geir Johnsen
TMR4120	Underwater Technology	Martin Ludvigsen
TMR4167	Marine Technology 2	Jørgen Amdahl
TMR4195	Design of Offshore Structures	Jørgen Amdahl
TMR4205	Buckling and Ultimate Collapse of Marine Structures	Jørgen Amdahl
TMR4225	Marine Operations	Trygve Kristiansen, Martin Ludvigsen and more
TMR4240	Marine Control Systems	Asgeir J. Sørensen
TMR4243	Marine Control Systems 2	Roger Skjetne
TMR4215	Sea Loads	Marilena Greco
TMR4217	Hydrodynamics of High-speed Marine Vehicles	Marilena Greco
TMR4290	Marine Power and Propulsion Systems	Roger Skjetne
TMR4505	Integrated Dynamic Analysis of Wind Turbines	Erin E. Bachynski
TMR4585	Underwater Technology (Specialization Subject)	Martin Ludvigsen
TTK4109	Guidance and Control of Vehicles	Thor I. Fossen
TTK4130	Modeling and Simulation	Lars S. Imsland
TTK4150	Nonlinear Control Systems	Kristin Y. Pettersen
TTK4225	Systems Theory, Introduction	Edmund F. Brekke
TTK4240	Industrial Electrotechnics	Marta Molinas
TTK7	Control and Application of Power Electronics Converters in Modern Power Systems	Marta Molinas

PhD degrees 2013-2016 – financed by NTNU AMOS

Name	Year	Gender	Topic	Supervisor
Belleter, Dennis	2016	M	Control of Underactuated Marine Vehicles in the Presence of Environmental Disturbances	KYP
Sørensen, Kim L.	2016	M	Autonomous Icing Protection Solution for Small Unmanned Aircraft – An Icing Detection, Anti-icing and De-icing Solution	TAJ

PhD degrees 2014-2016 – associated to NTNU AMOS

2016

Supervised by key scientists at NTNU AMOS

Name	Gender	Topic	Supervisor
Bø, Torstein I.	M	Scenario- and Optimization-based Control of Marine Electric Power Systems	TAJ
Candeloro, Mauro	M	Tools and Methods for Autonomous Operations on Seabed and Water Column Using Underwater Vehicles	AJS
Haring, Mark	M	Extremum-seeking Control, Convergence Improvements and Asymptotic Stability	TAJ
Kjerstad, Øivind K.	M	Dynamic Positioning of Marine Vessels in Ice	RS
Moe, Signe	F	Guidance and Control of Robot Manipulators and Autonomous Marine Robot	KYP
Nilssen, Ingunn	F	Integrated Environmental Mapping and Monitoring: A Methodological Approach for End-users	AJS
Storheim, Martin	M	Integral Line-of-sight Guidance and Control of Underactuated Marine Vehicles	JAM

Supervised by NTNU AMOS senior advisers Odd M. Faltinsen and Torgeir Moan - scholarship at CeSOS

Name	Gender	Topic	Supervisor
Acero, Wilson Ivan Guachamin	M	Assessment of Marine Operations for Offshore Wind Turbine Installation with Emphasis on Response-based Operational Limits	TM
Cheng, Zhengshun	M	Integrated Dynamic Analysis of Floating Vertical Axis Wind Turbines	TM
Lin, Li	F	Dynamic Analysis of the Installation of Monopiles for Offshore Wind Turbines	TM
Wan, Ling	M	Experimental and Numerical Study of a Combined Offshore Wind and Wave Energy Converter Concept	TM
Wu, Xiaopeng	M	Numerical Analysis of Anchor Handling and Fish Trawling Operations in a Safety Perspective	TM

2015

Supervised by key scientists at NTNU AMOS

Name	Gender	Topic	Supervisor
Fernandes, Daniel de A.	M	An Output Feedback Motion Control System for ROVs: Guidance Navigation and Control	AJS
Kelasidi, Eleni	F	Modeling, Control and Energy Efficiency of Underwater Snake Robots	KYP
Rezapour, Ehsan	M	Model-based Locomotion Control of Underactuated Snake Robots	KYP
Sanfilippo, Filippo	M	Alternative and Flexible Control Methods for Robotic Manipulators	KYP
Zhao, Bo	M	Particle Filter for Fault Diagnosis: Applications to Dynamic Positioning Vessel and Underwater Robotic	RS

Supervised by NTNU AMOS senior advisers Odd M. Faltinsen and Torgeir Moan - scholarship at CeSOS

Name	Gender	Topic	Supervisor
De Vaal, Jacobus	M	Aerodynamic Modelling of Floating Wind Turbines	TM
Fredriksen, Arnt G.	M	A Numerical and Experimental Study of a Two-dimensional Body with Moonpool in Waves and Current	OF

Name	Gender	Topic	Supervisor
Nejad, Amir Rasekhi	M	Dynamic Analysis and Design of Gearboxes in Offshore Wind Turbines in a Structural Reliability Perspective	TM
Wang, Kai	M	Modelling and Dynamic Analysis of a Semi-submersible Floating Vertical Axis Wind Turbine	TM

2014

Supervised by key scientists at NTNU AMOS

Name	Gender	Topic	Supervisor
Caharija, Walter	M	Integral Line-of-Sight Guidance and Control of Underactuated Marine Vehicles	KYP
Dukan, Fredrik	M	ROV Motion Control Systems	AJS
Kim, Ekaterina	F	Experimental and Numerical Studies Related to the Coupled Behaviour of Ice Mass and Steel During Accidental Collisions	JAM
Lekkas, Anastasios	M	Guidance and Path-planning Systems for Autonomous Vehicles	TIF
Veksler, Aleksander	M	Optimization-based Control of Diesel-electric Ships in Dynamic Positioning	TAJ

Supervised by NTNU AMOS senior advisers Odd M. Faltinsen and Torgeir Moan - scholarship at CeSOS

Name	Gender	Topic	Supervisor
An, Song	M	Theoretical and Experimental Studies of Wave Diffraction and Radiation Loads on a Horizontally Submerged Perforated Plate	OF
Bachynski, Erin E.	F	Design and Dynamic Analysis of Tension Leg Platform Wind Turbines	TM
Jiang, Zhiyu	M	Long-term Response Analysis of Wind Turbines with an Emphasis on Fault and Shutdown Conditions	TM
Kvittem, Marit I.	F	Modelling and Response Analysis for Fatigue Design of a Semi-submersible Wind Turbine	TM
Muliawan, Made J.	M	Design and Analysis of Combined Floating Wave and Wind Power Facilities, with Emphasis on Extreme Load Effects of the Mooring System	TM
Rogne, Øyvind Y.	M	Numerical and Experimental Investigation of a Hinged 5-Body Wave Energy Converter	TM
Tan, Xiang	F	Numerical Investigation of Ship's Continuous-mode Icebreaking in Level Ice	TM
Wang, Jingbo	M	Water Entry of Freefall Wedges-wedge Motions and Cavity Dynamics	OF

Master degrees in 2016

Name	Topic	Supervisor
Aakre, Øyvind Løberg	Development of a Dynamic Positioning System for Merlin WR200 ROV	Fossen, Thor Inge
Ai, Peng	Design and Hydrodynamic Analysis of a Semi-submersible with Two 5WM Wind Turbines	Gao, Zhen
Armstrong, Michael Andrew	Seismic Inversion for Identification of Soil Stiffness and Damping for Offshore Wind Turbines	Moan, Torgeir
Arnesen, Bent Oddvar	Motion Control Systems for ROVs	Schjølberg, Ingrid
Biørn-Hansen, Einar	Coupling of a 2D Boundary Element Method With a Local Analytical Solution to Deal with Geometrical Singularities	Greco, Marilena
Bjørne, Elias S.	Nonlinear Adaptive Motion Control and Model-error Analysis for Ships	Breivik, Morten
Bjørnø, Jon	Thruster-assisted Position Mooring of C/S Inocean Cat I Drillship	Skjetne, Roger
Brevik, Anders	Optimal Kontrol av Kontrollerbar Pitch Propell	Johansen, Tor Arne
Broen, Anders Kjeka	Real-time Harmonics Tracking for Stability Assessment of a Microgrid	Molinas, Marta
Brudvik, Baste	Icing Detection on Leading Edge of Aircraft Wings	Johansen, Tor Arne
Brusletto, Lars Sletbakk	Computer Vision Based Obstacle Avoidance for a Remotely Operated Vehicle	Ludvigsen, Martin

Name	Topic	Supervisor
Bua, Nils Haktor	Sway Control on a Surface Effect Ship	Hassani, Vahid
Castellanos, Stephanie Liefmann	Eco-physiological Responses of Cold-water Corals to Anthropogenic Sedimentation and Particle Shape	Johnsen, Geir
Deng, Shi	Numerical Simulations for Lift-off Operation of an Offshore Wind Turbine Monopile	Gao, Zhen
Efteland, Jørn Iversen	Underwater Acoustic Positioning System for Real-time Fish Tracking	Alfredsen, Jo Arve
Espedal, Mikal Hansson	Numerical Analysis of a Floating Wind Turbine	Kristiansen, Trygve
Finstad, Christian B	Peak-shaving Control of Loads on Diesel-generators in Hybrid Electric Ships	Skjetne, Roger
Fotland, Tore Jacobsen	Nødlanding for et Ubemannet Fly	Storvold, Rune
Frederich, Preben	Constrained Optimal Thrust Allocation for C/S Inocean Cat I Drillship	Skjetne, Roger
Frimanslund, Erik Kristian Thon	Feasibility of Deep-sea Mining Operation Within Norwegian Jurisdiction	Ludvigsen, Martin
Hektoen, Nikolai Mejdell	Model Predictive Waypoint Following for an UAV Using End-time Bisection	Imsland, Lars
Henriksen, Andreas Viggen	Camera-assisted Dynamic Positioning of ROVs	Skjetne, Roger
Henriksen, Vegard Wie	Three-axis Motion Compensated Crane Head Control	Johansen, Tor Arne
Hillestad, Gard	Design av et Utviklingsverktøy for Microgrids	Molinas, Marta
Holm, Jørgen Thode Gryteland	Analyse og Dimensjonering av Halsafjordens Strekkstag Understøttede Hengebro Utsatt for Støt fra Store Skip	Amdahl, Jørgen
Hugo, Åsmund Pedersen	Kinematic Control of Underwater Robotic System	Schjølberg, Ingrid
Huynh, Johnny Quang Tuan	Detailed Design of a Thruster Solution for a Small Mass-market Remotely Operated Underwater Vehicle	Ludvigsen, Martin
Håpnes, Sverre Julian Helmersen	Mapping of Demersal Fish and Benthos by AUC Equipped with Optical and Acoustic Imagers at 600 m Depth in Trondheimsfjorden	Johnsen, Geir
Islam, Md Touhidul	Design, Numerical Modelling and Analysis of a Semi-submersible Floater Supporting the DTU 10MW Wind Turbine	Gao, Zhen
Jacobsen, Nikolai Havikbotn	Application of RCM Principles to Identify Barriers in Design of Unmanned Engine Rooms for Oceangoing Merchant Vessels	Utne, Ingrid Bouwer
Jakobsen, June	The Tautra Cold-water Coral Reef- Mapping and Describing the Biodiversity of a Cold-water Coral Reef Ecosystem in the Trondheimsfjord by Use of Multi-beam Echo Sounding and Video Mounted on a Remotely Operated Vehicle	Johnsen, Geir
Koppenol, Boy Solo	Dynamic Analysis of a Floating Vertical Axis Wind Turbine Using the Actuator Cylinder Flow Theory	Gao, Zhen
Kristiansen, Aleksander V	Estimation of the Economic Effect of Implementing Reliabilty-centred Maintenance Onboard a Maritime Vessel	Utne, Ingrid Bouwer
Leimeister, Mareike	Rational Upscaling and Modelling of a Semi-submersible Floating Offshore Wind Turbine	Bachynski, Erin E.
Liu, Haobin	Stress Analysis of the Structural Interface Between the Spar and the Torus in the Combined Wind and Wave Energy Concept STC	Gao, Zhen
Lubis, Michael Binsar	Time Domain Simulation of Jack-up in Second Order Irregular Seas	Amdahl, Jørgen
Maastad, Marius	Numerical and Experimental Study of the Fred Olsen Wind Turbine Concept	Gao, Zhen
Malik, Mohibb Ghani	Hydrodynamic Modelling Effects on Fatigue Calculations for Monopile Offshore Wind Turbines	Gao, Zhen
Mellem, Adelaide	Smart Release Pods for Juvenile Lobster in Sea Ranching	Alfredsen, Jo Arve
Moe, Jostein Borgen	Autonomous Landing of Fixed-wing UAV in Net Suspended by Multirotor UAVs	Johansen, Tor Arne
Moe, Ole Harald	Analysis and Design of Bjørnafjorden TLP Supported Suspension Bridge Subjected to Large Ship Collisions and Extreme Environmental Loads	Amdahl, Jørgen
Molvær, Joar	A Unified Real-time Feature Extraction and Classification Process for a BCI Based on Empirical Mode Decomposition and Support Vector Machine	Molinas, Marta
Muren, Marit Maukon	Response Calculations of Semi-submersible Column Exposed to Slamming Loads	Amdahl, Jørgen
Myre, Helene	Collision Avoidance for Autonomous Surface Vehicles Using Velocity Obstacle and Set-based Guidance	Brekke, Edmund Førland

Name	Topic	Supervisor
Nahian, Nishat Al	Structural Analysis of the Gripper Connection During Monopile Installation	Gao, Zhen
Nesse, Ove	Wireless Surface Interface for Subsea Instrumentation	Alfredsen, Jo Arve
Nevstad, Sigurd Olav	Autonomous Landing of Fixed-wing UAV in Net Suspended by Multirotor UAVs	Johansen, Tor Arne
Omholt, Bjørn William	Direct Yaw Moment, Traction and Power Limit Control of a Four Wheel Independent Drive Electric (4WID-EV) Formula Student Race Car	Johansen, Tor Arne
Palm, Astrid Maria	Buckling and Load Shedding in Redundant Plated Ship Structures	Amdahl, Jørgen
Rabliås, Øyvind	Development of a new Navier-Stokes Solver Using a Generalized HPC Method for the Pressure Poisson Equation	Greco, Marilena
Rahman, Md. Rafiur	Numerical Modeling and Analysis of the Combined Wind and Wave Energy Concept SFC	Gao, Zhen
Reiersen, Lars M. Utnes	Investigation of Moonpool Resonance as Vessel Damping Device	Kristiansen, Trygve
Rist-Christensen, Ida	Autonomous Robotic Intervention Using ROV	Ludvigsen, Martin
Riste, Kristine Bøyum	Development of a Frequency-domain Model for Dynamic Analysis of the Floating Wind Turbine Concept - WindFloat	Gao, Zhen
Rolfseng, Jon Henning	Analysis of Accelerometric Datasets for Wind Turbine Monitoring	Utne, Ingrid Bouwer
Roy, Elizabeth	System Integration of Unmanned Aerial Vehicle with Thermal Camera	Fossen, Thor Inge
Ruud, Fredrik Jonsson	Autonomous Homing and Docking of AUV REMUS 100	Ludvigsen, Martin
Røine, Audun Gerhardsen	Three-axis Motion Compensated Crane Head Control	Johansen, Tor Arne
Røyland, Daniel	Dead Reckoning System for UAV Using RSSI and Extremum Seeking Control	Johansen, Tor Arne
Sandvik, Tarje Moe	Area Based Frequency Control in the Nordic Power System	Imsland, Lars
Sandøy, Stian Skaalvik	System Identification and State Estimation for ROV uDrone	Skjetne, Roger
Scheide, Audun Werner	Design and Analyze of a Pressure Vessel for an Underwater Remotely Operated Vehicle Produced by Injection Molding	Ludvigsen, Martin
Schwebe, Tjark Tilman	Dynamic Collapse of the Hull Girder in a Container Ship in Waves	Amdahl, Jørgen
Sharoni, Rotem	Marine Inverted Pendulum	Skjetne, Roger
Solstad, Torkil Eide	Improved User-experience for Control of ROVs	Skjetne, Roger
Spange, Joachim	Autonomous Docking for Marine Vessels Using a Lidar and Proximity Sensors	Skjetne, Roger
Steinsland, Solveig	Control Strategy for AHC Offshore Crane Systems	Fossen, Thor Inge
Strand, Anders Salberg	Wellhead Platform Subjected to Accidental Loads	Amdahl, Jørgen
Svendsen, Kristian Freng	Structural Design and Dynamic Analysis of a Tension Leg Platform Wind Turbine, Considering Elasticity in the Hull	Bachynski, Erin E.
Sørbø, Kjetil Hope	Autonomous Landing of Fixed-wing UAV in a Stationary Net	Johansen, Tor Arne
Tian, Xiaoshuang	Design, Numerical Modelling and Analysis of TLP Floater Supporting the DTU 10MW Wind Turbine	Gao, Zhen
Tsigkris, Efstathios	Dynamic Response Analysis of a Spar Floating Wind Turbine in Level Ice with Varying Thickness	Gao, Zhen
Ueland, Einar Skiftestad	Marine Autonomous Exploration Using a Lidar	Skjetne, Roger
Vamråk, Vegard Moesødegård	Sway Control on a Surface Effect Ship	Hassani, Vahid
Velarde, Joey	Design of Monopile Foundations to Support the DTU 10 MW Offshore Wind Turbine	Bachynski, Erin E.
Wille, Kristian Løken	Autonomous Sailboats	Hassani, Vahid
Worren, Fredrik	A Unified Real-time Feature Extraction and Classification Process for a BCI Based on Empirical Mode Decomposition and Support Vector Machine	Molinas, Marta
Xu, Dapeng	Numerical Modelling and Simulations for Lowering of an Offshore Wind Turbine Tripod	Gao, Zhen
Xue, Wenfei	Design, Numerical Modelling and Analysis of a Spar Floater Supporting the DTU 10MW Wind Turbine	Gao, Zhen
Øien, Stein-Inge Torset	Dynamic Positioning for Small Autonomous Surface Vessels	Johansen, Tor Arne
Århus, Gisle Hoel	Analysis and Design of Ship Collision Barriers on a Submerged Floating Tunnel Subjected to Large Ship Collisions	Amdahl, Jørgen

Innovation meetings in 2016

Date	Activity	Participants
3 March	Entrepreneurship – Perspectives from Silicon Valley, Prof. Jack Fuchs (one-day seminar)	PhD candidates and postdocs
8 September	The Story of TelCage, Oddbjørn Rødsten	PhD candidates and postdocs
18 October	From Idea to Market (half-day seminar), Tom Ivar Bern	PhD candidates and postdocs
3 November	Risk Mitigation in Entrepreneurial Ventures, Inge Hovd Gangås	PhD candidates and postdocs

Guest lectures and seminars by visitors to NTNU AMOS in 2016

Date	Speaker	Topic
27 January	Adj. Assoc. Prof. Ulrik D. Nielsen, Technical University of Denmark / NTNU AMOS	New Concepts for Shipboard Sea State Estimation
10 February	Prof. Karl H. Johansson, Royal Institute of Technology, Sweden / NTNU AMOS	Role of Plant Model Information in Large-scale Control Systems
17 February	Assistant Prof. John Hedengren, Brigham Young University, USA	Ensemble Model Predictive Control for Managed Pressure Drilling
1 April	Prof. Kanna Rajan, NTNU, Norway	NASA Spaceflight Missisons: What Goes On Behind-the-scenes?
29 March	Prof. Henrik O. Madsen, Technical University of Denmark	How Can We Support the New United Nations Sustainable Development Goals Through Research and Innovation
26 May	Prof. Murat Arcak, University of California, Berkeley, USA	Control Synthesis with Formal Methods: Exploiting System Structure for Scalability
30 May	Chris Meissen, University of California, Berkeley, USA	Performance and Safety Certification of Interconnected Systems
15 June	Assistant Prof. Ionela Prodan, LCIS, Grenoble INP, France	Optimization-based Control Design for Reliable Microgrid Energy Management and Flatness-based Nonlinear Control Strategies for Trajectory Tracking of Quadcopter Systems
24 June	Prof. Martin Guay, Queen's University, Canada	Design of High-performance Extremum-seeking Control Systems
25 August	Prof. Jeffrey Falzarano, Texas A&M University, USA	Nonlinear Ship Rolling Motion: the importance of Physical Modeling, Nonlinear Dynamics and Stochastic Dynamics
25 August	Prof. Ali Mosleh, University of California, Los Angeles, USA	Foundations of Risk Analysis and Application to Aviation Safety Management
27 September	Prof. E. E. Theotokoglou, National Technical University of Athens, Greece	Analysis of FRP Composite Structures in Offshore Wind Turbines and Other Offshore Structures
5 October	Monica Solem, Statoil Corporate Staff Safety & Security, Norway	Statoil's Global Risk Management, Including IT Security
18 October	Antonio Adaldo, KTH Royal Institute of Technology, Sweden	Multi-agent Coordination with Event-based Cloud Access
8 November	Prof. Tristan Perez, Queensland University of Technology, Australia	Dynamical System Behaviours - The Underlying Thread of My Current Research in Agriculture, Bio-inspired Guidance, and Trusted Autonomy
15 November	Dr Fumin Zhang, Georgia Institute of Technology, USA	Motion Tomography and Collective Mobile Sensing in the Ocean
15 November	Dr Pere Ridao, University of Girona, Spain	Intervention AUVs: Experiences and Challenges
29 November	Assistant Prof. Dimitra Panagou, University of Michigan, USA	A Distributed Semi-cooperative Coordination Protocol for Dynamic Multi-agent Systems

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
Nanyang Technological University, Singapore	KJ	Since 2014	Visiting Professor
National University of Singapore	TM	2002-2007	Keppel Professor
Technical University of Denmark	TIF	2013	Otto Mønsted Professor
University College London, UK	OF	Since 2005	Visiting Professor
University of California, Berkeley	KJ	2016-2017	Visiting Scholar
University of Porto, Portugal	KR	Since 2014	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
Association for the Advancement of Artificial Intelligence	KR	Since 2008	Member
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	MB	Since 2001	Member
Danish Society of Naval Architecture and Marine Engineering	UDN	Since 2011	Board Member
IEEE Power Electronics Society	MM	Since 2016	IEEE Humanitarian Board Member
Institute of Electrical and Electronics Engineers (IEEE)	KJ	Since 2013	Elected Fellow
Institute of Electrical and Electronics Engineers (IEEE)	KJ	2017-2019	Distinguished Lecturer
Institute of Electrical and Electronics Engineers (IEEE)	KYP	Since 2017	Elected Fellow
Institute of Electrical and Electronics Engineers (IEEE)	TIF	Since 2016	Elected Fellow
Int. Assoc. of Bridge and Structural Engineers	TM	Since 2001	Elected 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

Academy	Person	Period	Responsibility
Norwegian Scientific Academy for Polar Research	GJ	Since 2008	Member
Offshore Energy Center, Hall of Fame, Houston, USA	TM	Since 2002	Elected
Royal Academy of Engineering, UK	TM	1995	Elected 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

Publications in 2016

Book chapters

Antonelli, Gianluca; Fossen, Thor I.; Yoerger, D. Modeling and Control of Underwater Robotics. IN: *Springer Handbook of Robotics*. Springer 2016 ISBN 978-3-319-32550-7. P.1285-1304

Cheng, Zhengshun; Moan, Torgeir; Gao, Zhen. Dynamic response analysis of floating wind turbines with emphasis on vertical axis rotors. IN: *MARE-WINT*. Springer Publishing Company 2016 ISBN 978-3-319-39094-9. P.173-192

Fossen, Thor I.; Perez, Tristan. Model-based Ship Motion Control Design. IN: *Compendium of Ships Hydrodynamics. Practical Tools and Application*. Paris: Les Presses de l'ENSTA 2016 ISBN 978-2722509498.

Grip, Håvard Fjær; Fossen, Thor I.; Johansen, Tor Arne; Saberi, Ali. Nonlinear Observer for Attitude, Position and Velocity: Theory and Experiments. IN: *Multisensor Attitude Estimation: Fundamental Concepts and Applications*. CRC Press 2016 ISBN 9781498745710. P.291-314

Hansen, Jakob Mahler; Rohac, Jan; Sipos, Martin; Johansen, Tor Arne; Fossen, Thor I. Validation and Experimental Testing of Observers for Robust GNSS-Aided Inertial Navigation. IN: *Recent Advances in Robotic Systems*. INTECH2016 ISBN 978-953-51-2570-9.

Perez, Tristan; Fossen, Thor I. Hydrodynamic Models for Motion Control. IN: *Compendium of Ships Hydrodynamics. Practical Tools and Application*. Paris: Les Presses de l'ENSTA 2016 ISBN 978-2722509498.

Journal articles

Alver, Morten; Skøien, Kristoffer Rist; Føre, Martin; Aas, Turid Synnøve; Oehme, Maike; Alfredsen, Jo Arve. Modelling of surface and 3D pellet distribution in Atlantic salmon (Salmo salar L.) cages. *Aquacultural Engineering* 2016, Volume 72-73. P.20-29

Andersson, Leif Erik; Scibilia, Francesco; Imsland, Lars Struen. An estimation-forecast set-up for iceberg drift prediction. *Cold Regions Science and Technology* 2016, Volume 131. P.88-107

Antuono, M; Colicchio, Giuseppina. Delayed Over-Relaxation for iterative methods. *Journal of Computational Physics* 2016, Volume 321.p.892-907

Bø, Torstein Ingebrigtsen; Johansen, Tor Arne. Battery power smoothing control in a marine electric power plant using non-linear model predictive control. *IEEE Transactions on Control Systems Technology* 2016, Volume PP.(99)

Bø, Torstein Ingebrigtsen; Johansen, Tor Arne. Dynamic Safety Constraints by Scenario Based Economic Model Predictive Control of Marine Electric Power Plants. *IEEE Transactions on Transportation Electrification* 2016

Bø, Torstein Ingebrigtsen; Johansen, Tor Arne; Sørensen, Asgeir Johan; Mathiesen, Eirik. Dynamic consequence analysis of marine electric power plant in dynamic positioning. *Applied Ocean Research* 2016, Volume 57. P.30-39

Caharija, Walter; Pettersen, Kristin Ytterstad; Bibuli, Marco; Calado, Pável; Zereik, Enrica; Braga, Jose; Gravdahl, Jan Tommy; Sørensen, Asgeir Johan; Milovanovic, Milan; Bruzzone, Gabriele. Integral Line-of-Sight Guidance and Control of Underactuated Marine Vehicles: Theory, Simulations and Experiments. *IEEE Transactions on Control Systems Technology* 2016, Volume 24.(5)p.1623-1642

Cheng, Zhengshun; Madsen, Helge A.; Gao, Zhen; Moan, Torgeir. Aerodynamic Modeling of Offshore Vertical Axis Wind Turbines using the Actuator Cylinder Method. *Energy Procedia* 2016, Volume 94. P.531-543

Cheng, Zhengshun; Madsen, Helge A.; Gao, Zhen; Moan, Torgeir. Numerical Study on Aerodynamic Damping of Floating Vertical Axis Wind Turbines. *Journal of Physics, Conference Series* 2016, Volume 753.

Cho, Seongpil; Gao, Zhen; Moan, Torgeir. Model-based fault detection of blade pitch system in floating wind turbines. *Journal of Physics, Conference Series* 2016, Volume 753.

Cristofaro, Andrea. Uncertain parameter estimation for a class of nonlinear systems using a polynomial representation of outputs. *Journal of the Franklin Institute* 2016, Volume 353.(17) p.4652-4666

Cronin, Heather; Cohen, Jonathan H.; Berge, Jørgen; Johnsen, Geir; Moline, Mark A. Bioluminescence as an ecological factor during high Arctic polar night. *Scientific Reports* 2016, Volume 6.

Datta, N; Siddiqui, Mohd Atif. Hydroelastic analysis of axially loaded Timoshenko beams with intermediate end fixities under hydrodynamic slamming loads. *Ocean Engineering* 2016, Volume 127.p.124-134

Ersdal, Anne Mai; Imsland, Lars Struen; Uhlen, Kjetil. Model Predictive Load-Frequency Control. *IEEE Transactions on Power Systems* 2016, Volume 31.(1)p.777-785

Ersdal, Anne Mai; Imsland, Lars Struen; Uhlen, Kjetil; Fabozzi, Davide; Thornhill, Nina F. Model predictive load–frequency control taking into account imbalance uncertainty. *Control Engineering Practice* 2016, Volume 53. P.139-150

Etemaddar, Mahmoud; Blanke, Mogens; Gao, Zhen; Moan, Torgeir. Response analysis and comparison of a spar-type floating offshore wind turbine and an onshore wind turbine under blade pitch controller faults. *Wind Energy* 2016, Volume 19.(1)p.35-50

Faltinsen, Odd Magnus; Lukovsky, Ivan A; Timokha, Alexander. Resonant sloshing in an upright annular tank. *Journal of Fluid Mechanics* 2016, Volume 804.p.608-645

Faltinsen, Odd Magnus; Timokha, Alexander. Undamped eigenperiods of a sea-based gravity monotower. *Applied Mathematical Modelling* 2016, Volume 40.(19-20) P.8217-8243

Firoozkoohi, Reza; Faltinsen, Odd Magnus; Arslan, Tufan. Investigation of finite water depth sloshing in a tank in the presence of slat screens using model test and CFD. *International Journal of Offshore and Polar Engineering* 2016, Volume 26.(2)p.146-153

Førde, Henny; Forbord, Silje; Handå, Aleksander; Fossberg, Julia; Arff, Johanne; Johnsen, Geir; Reitan, Kjell Inge. Development of bryozoan fouling on cultivated kelp (Saccharina latissima) in Norway. *Journal of Applied Phycology* 2016, Volume 28.(2) P.1225-1234

Føre, Martin; Alver, Morten; Alfredsen, Jo Arve; Marafioti, Giancarlo; Senneset, Gunnar; Birkevold, Jens; Willumsen, Finn Victor; Lange, Guttorm; Espmark, Åsa Maria Olofsdotter; Terjesen, Bendik Fyhn. Modelling growth performance and feeding behaviour of Atlantic salmon (Salmo salar L.) in commercial-size aquaculture net pens: Model details and validation through full-scale experiments. *Aquaculture* 2016, Volume 464.p.268-278

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, Volume 1.(1)p.36-51

Geoffroy, Maxime; Cottier, Finlo Robert; Berge, Jørgen; Inall, Mark E. AUV-based acoustic observations of the distribution and patchiness of pelagic scattering layers during midnight sun. *ICES Journal of Marine Science* 2016

Ghane, Mahdi; Rasekhi Nejad, Amir; Blanke, Mogens; Gao, Zhen; Moan, Torgeir. Statistical fault diagnosis of wind turbine drivetrain applied to a 5MW floating wind turbine. *Journal of Physics, Conference Series* 2016, Volume 753.

Gryning, Mikkel P. S.; Wu, Qiuwei; Kocewiak, Lukaz; Niemann, Hans Henrik; Blanke, Mogens. Stability Boundaries for Offshore Wind Park Distributed Voltage Control. *IEEE Transactions on Control Systems Technology* 2016

Grøtli, Esten Ingar; Johansen, Tor Arne. Motion- and Communication-Planning of Unmanned Aerial Vehicles in Delay Tolerant Network using Mixed-Integer Linear Programming. *Modeling, Identification and Control* 2016, Volume 37.(2)p.77-97

Guachamin Acero, Wilson Ivan; Gao, Zhen; Moan, Torgeir. Assessment of the Dynamic Responses and Allowable Sea States for a Novel Offshore Wind Turbine Tower and Rotor Nacelle Assembly Installation Concept Based on the Inverted Pendulum Principle. *Energy Procedia* 2016, Volume 94.p.61-71

Guachamin Acero, Wilson Ivan; Li, Lin; Gao, Zhen; Moan, Torgeir. Methodology for assessment of the operational limits and operability of marine operations. *Ocean Engineering* 2016, Volume 125. P.308-327

Haring, Mark; Johansen, Tor Arne. Asymptotic stability of perturbation-based extremum-seeking control for nonlinear plants. *IEEE Transactions on Automatic Control* 2016, Volume PP.(99)

Haugen, Joakim; Imsland, Lars Struen. Monitoring Moving Objects Using Aerial Mobile Sensors. *IEEE Transactions on Control Systems Technology* 2016, Volume 24.(2) P.475-486

Hegde, Jeevith; Utne, Ingrid Bouwer; Schjølberg, Ingrid. Development of collision risk indicators for autonomous subsea inspection maintenance and repair. *Journal of Loss Prevention in the Process Industries* 2016 (44)p.440-452

Horn, Jan-Tore H.; Krokstad, Jørgen R; Amdahl, Jørgen. Hydro-Elastic Contributions to Fatigue Damage on a Large Monopile. *Energy Procedia* 2016, Volume 94.p.102-114

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, Volume 39.(8) p.1777-1789

Hu, Zhiqiang; Wang, Ge; Yao, Qi; Yu, Zhaolong. Rapid prediction of structural responses of double-bottom structures in shoal grounding scenario. *Journal of Marine Science and Application* 2016, Volume 15.(1)p.73-85

Johansen, Tor Arne; Fossen, Thor I. Nonlinear Observer for Tightly Coupled Integration of Pseudorange and Inertial Measurements. *IEEE Transactions on Control Systems Technology* 2016, Volume 24.(6)p.2199-2206

Johansen, Tor Arne; Fossen, Thor I.; Goodwin, Graham C. Three-stage filter for position estimation using pseudorange measurements. *IEEE Transactions on Aerospace and Electronic Systems* 2016, Volume 52.(4)p.1631-1643

Johansen, Tor Arne; Perez, Tristan; Cristofaro, Andrea. Ship collision avoidance and COLREGS compliance using simulation-based control behavior selection with predictive hazard assessment. *IEEE transactions on intelligent transportation systems (Print)* 2016, Volume 17.(12)p.3407-3422

Kelasidi, Eleni; Jesmani, Mansoureh; Pettersen, Kristin Ytterstad; Gravdahl, Jan Tommy. Multi-objective optimization for efficient motion of underwater snake robots. *Artificial Life and Robotics* 2016, Volume 21.(4) P.411-422

Kim, Ekaterina; Amdahl, Jørgen. Discussion of assumptions behind rule-based ice loads due to crushing. *Ocean Engineering* 2016, Volume 119. P.249-261

Kim, Ekaterina; Storheim, Martin; Amdahl, Jørgen; Løset, Sveinung; von Bock und Polach, Rüdiger Ulrich Franz. Laboratory experiments on shared-energy collisions between freshwater ice blocks and a floating steel structure. *Ships and Offshore Structures* 2016

Kjerstad, Øivind Kåre; Skjetne, Roger. Disturbance rejection by acceleration feedforward for marine surface vessels. *IEEE Access* 2016, Volume 4. P.2656-2669

Kohl, Anna Magdalena; Kelasidi, Eleni; Mohammadi, Alireza; Maggiore, Manfredi; Pettersen, Kristin Ytterstad. Planar maneuvering control of underwater snake robots using virtual holonomic constraints. *Bioinspiration & Biomimetics* 2016, Volume 11.(6)

Kohl, Anna; Pettersen, Kristin Ytterstad; Kelasidi, Eleni; Gravdahl, Jan Tommy. Planar path following of underwater snake robots in the presence of ocean currents. *IEEE Robotics and Automation Letters* 2016, Volume 1.(1)p.383-390

Kufoalor, D. Kwame Minde; Imsland, Lars Struen; Johansen, Tor Arne. Efficient implementation of step response models for embedded Model Predictive Control. *Computers and Chemical Engineering* 2016, Volume 90.p.121-135

Leimester, Mareike; Bachynski, Erin Elizabeth; Muskulus, Michael; Thomas, Philipp. Rational upscaling of a semi-submersible floating platform supporting a wind turbine. *Energy Procedia* 2016, Volume 94. P.434-442

Li, Lin; Gao, Zhen; Moan, Torgeir. Analysis of Lifting Operation of a Monopile Considering Vessel Shielding Effects in Short-crested Waves. *International Journal of Offshore and Polar Engineering* 2016, Volume 26.(04)p.408-416

Li, Lin; Gao, Zhen; Moan, Torgeir. Operability Analysis of Monopile Lowering Operation Using Different Numerical Approaches. *International Journal of Offshore and Polar Engineering* 2016, Volume 26.(2)p.88-99

Li, Lin; Guachamin Acero, Wilson Ivan; 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-Transactions of The Asme* 2016, Volume 138.(4) VAVis.L_Suppl 041902.

Li, Peng; Faltinsen, Odd Magnus; Lugni, Claudio. Nonlinear vertical accelerations of a floating torus in regular waves. *Journal of Fluids and Structures* 2016, Volume 66. P.589-608

Li, Qinyuan; Gao, Zhen; Moan, Torgeir. Modified Environmental Contour Method for Predicting Long-term Extreme Responses of Bottom-fixed Offshore Wind Turbines. *Marine Structures* 2016, Volume 48.p.15-32

Lotsberg, Inge; Sigurdsson, Gudfinnur; Fjeldstad, Arne; Moan, Torgeir. Probabilistic methods for planning of inspection for fatigue cracks in offshore structures. *Marine Structures* 2016, Volume 46. P.167-192

Ludvigsen, Martin; Sørensen, Asgeir Johan. Towards integrated autonomous underwater operations for ocean mapping and monitoring. *Annual Reviews in Control* 2016, Volume 42. P.145-157

Ma, Leixin; Hu, Ke; Fu, Shixiao; Moan, Torgeir; Li, Runpei. A hybrid empirical-numerical method for hydroelastic analysis of a floater-and-net system. *Journal of Ship Research* 2016, Volume 60.(1) P.14-29

Maree, Johannes Philippus; Imsland, Lars Struen. Combined economic and regulatory predictive control. *Automatica* 2016, Volume 69.p.342-347

Maree, Johannes Philippus; Imsland, Lars Struen; Jouffroy, Jerome. On convergence of the unscented Kalman-Bucy filter using contraction theory. *International Journal of Systems Science* 2016, Volume 47.(8)p.1816-1827

Michailidis, Konstantinos; Gao, Zhen; Moan, Torgeir. Experimental and numerical study of the response of the offshore combined wind/wave energy concept SFC in extreme environmental conditions. *Marine Structures* 2016, Volume 50.p.35-54

Michailidis, Konstantinos; Gao, Zhen; Moan, Torgeir. Experimental study of the functionality of a semisubmersible wind turbine combined with flap-type Wave Energy Converters. *Renewable Energy* 2016, Volume 93.p.675-690

Moe, Signe; Antonelli, Gianluca; Teel, Andrew R.; Pettersen, Kristin Ytterstad; Schrimpf, Johannes. Set-based Tasks within the Singularity-robust Multiple Task-priority Inverse Kinematics Framework: General Formulation, Stability Analysis and Experimental Results. *Frontiers in Robotics and AI* 2016, Volume 3.(16)

Mohammadi, Alireza; Rezapour, Ehsan; Maggiore, Manfredi; Pettersen, Kristin Ytterstad. Maneuvering Control of Planar Snake Robots Using Virtual Holonomic Constraints. *IEEE Transactions on Control Systems Technology* 2016, Volume 24.(3)p.884-899

Montazeri, Najmeh; Nielsen, Ulrik Dam; Jensen, Jørgen Juncher. Estimation of wind sea and swell using shipboard measurements - A refined parametric modelling approach. *Applied Ocean Research* 2016, Volume 54.p.73-86

Nielsen, Kræn Vodder; Blanke, Mogens; Eriksson, Lars; Vejlgaard-Laursen, Morten. Control-Oriented Model of Molar Scavenge Oxygen Fraction for Exhaust Recirculation in Large Diesel Engines. *Journal of Dynamic Systems Measurement, and Control* 2016, Volume 139.(2)

Nielsen, Ulrik Dam. A Review of Sea State Estimation Procedures Based on Measured Vessel Responses. *Proceedings of The Japan Society of Naval Architects and Ocean Engineers* 2016

Nielsen, Ulrik Dam; Bach, Kasper Følsnss; Iseki, Toshio. Improved Wave-vessel Transfer Functions by Uncertainty Modelling. *The Journal of Japan Institute of Navigation* 2016, Volume 134. P.134-137

Ommani, Babak; Kristiansen, Trygve; Faltinsen, Odd Magnus. Simplified CFD modeling for bilge keel force and hull pressure distribution on a rotating cylinder. *Applied Ocean Research* 2016, Volume 58.p.253-265

Osterloff, Jonas; Nilssen, Ingunn; Eide, Ingvar; Figueiredo, Marcia AO; Tamega, Frederico TS; Nattkemper, Tim W. Computational Visual Stress Level Analysis of Calcareous Algae Exposed to Sedimentation. *PLoS ONE* 2016, Volume 11.(6)

Osterloff, Jonas; Nilssen, Ingunn; Nattkemper, Tim W. A computer vision approach for monitoring the spatial and temporal shrimp distribution at the LoVe observatory. *Methods in oceanography* 2016, Volume 15-16.p.114-128

Prpic-Orsic, Jasna; Faltinsen, Odd Magnus; Parunov, J. Influence of operability criteria limiting values on ship speed. *Brodogradnja* 2016, Volume 67.(3)p.37-58

Prpic-Orsic, Jasna; Vettor, Roberto; Faltinsen, Odd Magnus; Guedes Soares, Carlos. The influence of route choice and operating conditions on fuel consumption and CO2 emission of ships. *Journal of Marine Science and Technology* 2016, Volume 21.(3)p.434-457

Rasekhi Nejad, Amir; Bachynski, Erin Elizabeth; Li, Lin; Moan, Torgeir. Correlation between Acceleration and Drivetrain Load Effects for Monopile Offshore Wind Turbines. *Energy Procedia* 2016, Volume 94. P.487-496

Rasekhi Nejad, Amir; Guo, Yi; Gao, Zhen; Moan, Torgeir. Development of a 5 MW reference gearbox for offshore wind turbines. *Wind Energy* 2016, Volume 19.(6)p.1089-1106

Rasekhi Nejad, Amir; Jiang, Zhiyu; Gao, Zhen; Moan, Torgeir. Drivetrain load effects in a 5-MW bottom-fixed wind turbine under blade-pitch fault condition and emergency shutdown. *Journal of Physics, Conference Series* 2016, Volume 753.(11)

Rejani Miyazaki, Michel; Sørensen, Asgeir Johan; Lefebvre, Nicolas; Yum, Koosup; Pedersen, Eilif. Hybrid modeling of strategic loading of a marine hybrid power plant with experimental validation. *IEEE Access* 2016, Volume 4.

Rejani Miyazaki, Michel; Sørensen, Asgeir Johan; Vartdal, Bjørn Johan. Reduction of fuel consumption on hybrid marine power plants by strategic loading with energy storage devices. *IEEE Power and Energy Technology Systems Journal* 2016, Volume 3.(4)p. 207-217

Rezapour, Ehsan; Pettersen, Kristin Ytterstad; Gravdahl, Jan Tommy; Hofmann, Andreas. Formation Control of Underactuated Bio-inspired Snake Robots. *Artificial Life and Robotics* 2016, Volume 21.(3) P.282-294

Rokseth, Børge; Skjong, Stian; Pedersen, Eilif. Modeling of Generic Offshore Vessel in Crane Operations With Focus on Strong Rigid Body Connections. *IEEE Journal of Oceanic Engineering* 2016, Volume PP.(99)p.1-23

Rotondo, Damiano; López-Estrada, Francisco Ronay; Nejjari, Fatiha; Ponsart, Jean-Christophe; Theilliol, Didier; Puig, Vicenç. Actuator multiplicative fault estimation in discrete-time LPV systems using switched observers. *Journal of the Franklin Institute* 2016, Volume 353.(13)p.3176-3191

Rotondo, Damiano; Nejjari, Fatiha; Puig, Vicenç. Fault tolerant control of a proton exchange membrane fuel cell using Takagi–Sugeno virtual actuators. *Journal of Process Control* 2016, Volume 45.p.12-29

Sanfilippo, Filippo; Hatledal, Lars Ivar; Styve, Arne; Pettersen, Kristin Ytterstad; Zhang, Houxiang. Integrated Flexible Maritime Crane Architecture for the Offshore Simulation Centre AS (OSC): A Flexible Framework for Alternative Maritime Crane Control Algorithms. *IEEE Journal of Oceanic Engineering* 2016, Volume 41.(2)p.450-461

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

Skjong, Espen; Suul, Jon Are Wold; Molinas Cabrera, Maria Marta; Johansen, Tor Arne. Optimal Compensation of Harmonic Propagation in a Multi-Bus Microgrid. *The Renewable Energies and Power Quality Journal (RE&PQJ)* 2016

Skjong, Espen; Suul, Jon Are Wold; Rygg, Atle; Johansen, Tor Arne; Molinas Cabrera, Maria Marta. System-Wide Harmonic Mitigation in a Diesel Electric Ship by Model Predictive Control. *IEEE transactions on industrial electronics (1982. Print)* 2016, Volume 63.(7)p.4008-4019

Skjong, Espen; Volden, Rune; Rødskar, Egil; Molinas Cabrera, Maria Marta; Johansen, Tor Arne; Cunningham, Joseph. Past, Present and Future Challenges of the Marine Vessel's Electrical Power System. *IEEE Transactions on Transportation Electrification* 2016

Skøien, Kristoffer Rist; Alver, Morten; Zolich, Artur Piotr; Alfredsen, Jo Arve. Feed spreaders in sea cage aquaculture – Motion characterization and measurement of spatial pellet distribution using an unmanned aerial vehicle. *Computers and Electronics in Agriculture* 2016, Volume 129.p.27-36

Smilden, Emil; Eliassen, Lene; Sørensen, Asgeir Johan. Wind Model for Simulation of Thrust Variations on a Wind Turbine. *Energy Procedia* 2016, Volume 94.p.306-318

Song, Ming; Kim, Ekaterina; Amdahl, Jørgen; Ma, Jun; Huang, Yi. A comparative analysis of the fluid-structure interaction method and the constant added mass method for ice-structure collisions. *Marine Structures* 2016, Volume 49.p.58-75

Sousa, Lara L; Lopez-Castejon, Francisco; Gilabert, Javier; Relvas, Paulo; Couto, Ana; Queiroz, Nuno; Caldas, Renato; Dias, Paulo Sousa; Dias, Hugo; Faria, Margarida; Ferreira, Filipe; Ferreira, Antonio Sergio; Fortuna, Joao; Gomes, Ricardo Joel; Loureiro, Bruno; Martins, Ricardo; Madureira, Luis; Neiva, Jorge; Oliveira, Marina; Pereira, Joao; Pinto, Jose; Py, Frederic; Queiros, Hugo; Silva, Daniel; Sujit, P. B.; Zolich, Artur Piotr; Johansen, Tor Arne; Sousa, Joao Borges de; Rajan, Kanna. Integrated monitoring of Mola mola behaviour in space and time. *PLoS ONE* 2016, Volume 11.(8)

Strand, Ida Marlen; Sørensen, Asgeir Johan; Volent, Zsolt; Lader, Pål. Experimental study of current forces and deformations on a half ellipsoidal closed flexible fish cage. *Journal of Fluids and Structures* 2016, Volume 65.p.108-120

Theisen, Lukas R. S.; Niemann, Hans Henrik; Santos, Illmar F.; Galeazzi, Roberto; Blanke, Mogens. Modelling and identification for control of gas bearings. *Mechanical systems and signal processing* 2016, Volume 70-71. P.1150-1170

Timokha, Alexander. Analytically approximate natural sloshing modes and frequencies for an upright circular container with poles. *Journal of Engineering Mathematics* 2016, Volume 101.(1)p.47-54

Timokha, Alexander. The Bateman-Luke variational formalism in sloshing with rotational flows. *Natsional'na Akademiya Nauk Ukrainy. Dopovidi: naukovyi zhurnal* 2016 (4)p.30-34

Timokha, Alexander; Raynovskyy, Igor. Resonant liquid sloshing in an upright circular tank performing a periodic motion. *Journal of Computational & Applied Mathematics* 2016 (4 (122)) P.71-82

Veksler, Aleksander Vladimirovitsj; Johansen, Tor Arne; Borrelli, Francesco; Realfsen, Bjørnar. Dynamic positioning with model predictive control. *IEEE Transactions on Control Systems Technology* 2016, Volume 24.(4) P.1340-1353

Veksler, Aleksander Vladimirovitsj; Johansen, Tor Arne; Skjetne, Roger; Mathiesen, Eirik. Thrust Allocation with Dynamic Power Consumption Modulation for Diesel-Electric Ships. *IEEE Transactions on Control Systems Technology* 2016, Volume 24.(2)p.578-593

Wan, Ling; Gao, Zhen; Moan, Torgeir; Lugni, Claudio. Comparative experimental study of the survivability of a combined wind and wave energy converter in two testing facilities. *Ocean Engineering* 2016, Volume 111.p.82-94

Wan, Ling; Gao, Zhen; Moan, Torgeir; Lugni, Claudio. Experimental and numerical comparisons of hydrodynamic responses for a combined wind and wave energy converter concept under operational conditions. *Renewable Energy* 2016, Volume 93.p.87-100

Wang, Kai; Moan, Torgeir; Hansen, Martin Otto Laver. Stochastic dynamic response analysis of a floating vertical-axis wind turbine with a semi-submersible floater. *Wind Energy* 2016, Volume 19.(10)p.1853-1870

Wu, Chih-Hua; Faltinsen, Odd Magnus; Chen, Bang-Fuh. Dynamics of vortex evolution in a 2D baffled tank. *Computers and Mathematics with Applications* 2016, Volume 71.(1) P.1-28

Yu, Zhaolong; Amdahl, Jørgen. Full six degrees of freedom coupled dynamic simulation of ship collision and grounding accidents. *Marine Structures* 2016, Volume 47. P.1-22

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

Yu, Zhaolong; Shen, Yugao; Amdahl, Jørgen; Greco, Marilena. Implementation of Linear Potential-Flow Theory in the 6DOF Coupled Simulation of Ship Collision and Grounding Accidents. *Journal of Ship Research* 2016, Volume 60.(3)p.1-26

Conference papers

Ahmadi Moshkenani, Parisa; Olaru, Sorin; Johansen, Tor Arne. Further Results on the Exploration of Combinatorial Tree in Multi-Parametric Quadratic Programming. *European Control Conference*; 2016-06-29 - 2016-07-01

Ahmadi Moshkenani, Parisa; Johansen, Tor Arne; Olaru, Sorin. On Degeneracy in Exploration of Combinatorial Tree in Multi-Parametric Quadratic Programming. *I E E E Conference on Decision and Control. Proceedings* 2016

Albert, Anders; Imsland, Lars Struen; Haugen, Joakim. Numerical Optimal Control Mixing Collocation with Single Shooting: A Case Study. *IFAC-PapersOnLine* 2016 ;Volume 49.(7) P.290-295

Amdahl, Jørgen; Holmas, Tore. ISUM for Offshore Frame Structures. IN: *ASME 2016 35th International Conference on Ocean, Offshore and Arctic Engineering - Volume 9: Prof. Norman Jones Honoring Symposium on Impact Engineering; Prof. Yukio Ueda Honoring Symposium on Idealized Nonlinear Mechanics for Welding and Strength of Structures*. ASME Press 2016 ISBN 978-0-7918-5000-8.

Andersson, Leif Erik; Imsland, Lars Struen; Scibilia, Francesco. An Iceberg Drift Prediction Study Offshore Newfoundland. IN: *Arctic Technology Conference 2016 (Proceedings)*. 2016 ISBN 978-1-61399-489-4.

Andersson, Leif Erik; Scibilia, Francesco; Imsland, Lars Struen. Estimation of systems with oscillating inputs - applied to iceberg drift forecast. IN: *2016 IEEE Conference on Control Applications (CCA)*. IEEE conference proceedings 2016 ISBN 978-1-5090-0756-1.

Andersson, Leif Erik; Imsland, Lars Struen; Scibilia, Francesco. The Moving Horizon Estimator Used in Iceberg Drift Estimation and Forecast. IN: *Control Conference (ECC), 2016 European*. IEEE 2017 ISBN 978-1-5090-2591-6.

Bachynski, Erin Elizabeth; Thys, Maxime; Sauder, Thomas Michel; Chabaud, Valentin Bruno; Sæther, Lars Ove. Real-time hybrid model testing of a braceless semi-submersible wind turbine. Part II: Experimental results. IN: *ASME 2016 35th International Conference on Ocean, Offshore and Arctic Engineering - Volume 6: Ocean Space Utilization; Ocean Renewable Energy*. ASME Press 2016 ISBN 978-0-7918-4997-2.

Baldi, Pietro; Blanke, Mogens; Castaldi, Paolo; Mimmo, Nicola; Simani, Silvio. Combined Geometric and Neural Network Approach to Generic Fault Diagnosis in Satellite Actuators and Sensors. *IFAC-PapersOnLine* 2016 ;Volume 49.(17) P.432-437

Belleter, Dennis Johannes Wouter; Paliotta, Claudio; Maggiore, Manfredi; Pettersen, Kristin Ytterstad. Path Following for Underactuated Marine Vessels. *IFAC-PapersOnLine* 2016 ;Volume 49.(18) P.289-295

Berge, Jørgen; Geoffroy, Maxime; Johnsen, Geir; Cottier, Finlo Robert; Bluhm, Bodil; Vogedes, Daniel Ludwig. Ice-tethered observational platforms in the Arctic Ocean pack ice. *IFAC-PapersOnLine* 2016 ;Volume 49.(23) P.494-499

Borup, Kasper Trolle; Fossen, Thor I.; Johansen, Tor Arne. A Nonlinear Model-Based Wind Velocity Observer for Unmanned Aerial Vehicles. *IFAC-PapersOnLine* 2016 ;Volume 49.(18) P.276-283

Brodtkorb, Astrid H.; Teel, Andrew R.; Sørensen, Asgeir Johan. Hybrid Observer Combining Measurements of Different Fidelities. *IFAC-PapersOnLine* 2016 ;Volume 49.(23) P.506-511

Brodtkorb, Astrid H.; Værnø, Svenn Are Tutturen; Teel, Andrew R.; Sørensen, Asgeir Johan; Skjetne, Roger. Hybrid observer for improved transient performance of a marine vessel in dynamic positioning. *IFAC-PapersOnLine* 2016 ;Volume 49.(18) P.345-350

Broen, Anders Kjeka; Amin, Mohammad; Skjong, Espen; Molinas Cabrera, Maria Marta. Instantaneous frequency tracking of harmonic distortions for grid impedance identification based on Kalman filtering. IN: *2016 IEEE 17th Workshop on Control and Modeling for Power Electronics, COMPEL 2016 : Proceedings*. IEEE conference proceedings 2016 ISBN 978-1-5090-1815-4.

Bryne, Torleiv Håland; Rogne, Robert Harald; Fossen, Thor I.; Johansen, Tor Arne. Attitude and Heave Determination on Ships using MEMS-based Inertial Measurements. *Elsevier IFAC Publications / IFAC Proceedings series* 2016 ;Volume 49.(23) P.568-575

Candeloro, Mauro; Lekkas, Anastasios M.; Hegde, Jeevith; Sørensen, Asgeir Johan. A 3D Dynamic Voronoi Diagram-Based Path-Planning System for UUVs. IN: *OCEANS 2016 MTS/IEEE Monterey*. IEEE conference proceedings 2016 ISBN 978-1-5090-1537-5.

Choi, Ju-hyuck; Jensen, Jørgen Juncher; Nielsen, Ulrik Dam. A Study on the uncertainty and sensitivity in numerical simulation of parametric roll. IN: *Proceedings of the 13th International Symposium on PRActical Design of Ships and Other Floating Structures (PRADS' 2016)*. Danmarks Tekniske Universitet, DTU 2016 ISBN 978-87-7475-473-2.

Colicchio, Giuseppina; Greco, Marilena; Faltinsen, Odd Magnus. Underwater explosions near marine structures: a Dynamics Fluid Structure Domain-Decomposition strategy. IN: *Proceedings - 31st International Workshop on Water Waves and Floating Bodies*. 2016 ISBN 978-1-60785-381-7.

Cristofaro, Andrea; Johansen, Tor Arne. An unknown input observer based control allocation scheme for icing diagnosis and accommodation in overactuated UAVs. *European Control Conference*; 2016-06-29 - 2016-07-01

Cristofaro, Andrea; Polycarpou, Marios M.; Johansen, Tor Arne. Fault diagnosis and fault-tolerant control allocation for a class of nonlinear systems with redundant inputs. *I E E E Conference on Decision and Control. Proceedings* 2016 ;Volume 2016-February. P.5117-5123

Eidsvik, Ole Alexander Nørve; Schjølberg, Ingrid. Determination of Hydrodynamic Parameters for Remotely Operated Vehicles. IN: *ASME 2016 35th International Conference on Ocean, Offshore and Arctic Engineering - Volume 7: Ocean Engineering*. ASME Press 2016 ISBN 978-0-7918-4998-9.

Eidsvik, Ole Alexander Nørve; Schjølberg, Ingrid. Time Domain Modeling of ROV Umbilical using Beam Equations. *IFAC-PapersOnLine* 2016 ;Volume 49.(23) P.452-457

Eriksen, Bjørn-Olav Holtung; Breivik, Morten; Pettersen, Kristin Ytterstad; Syre Wiig, Martin. A Modified Dynamic Window Algorithm for Horizontal Collision Avoidance for AUVs. IN: *Proceedings of 2016 IEEE Conference on Control Applications (CCA)*. IEEE conference proceedings 2016 ISBN 978-150900755-4. P.499-506

Faltinsen, Odd Magnus. Hydrodynamics of fish farms and marine animals. *12th International Conference on Hydrodynamics, ICHD2016*; 2016-09-18 - 2016-09-23

Faltinsen, Odd Magnus. Modelling of manoeuvring in calm water and waves. *2nd International Meeting on Recent Advances in Prediction Techniques for Safe Manoeuvring of Ships and Submarines*; 2016-11-17 - 2016-11-18

Flåten, Andreas Lindahl; Brekke, Edmund Førland. Performance Prediction of Tracking Sensors for Surface Vehicle Collision Avoidance. IN: *Proceedings of the 19th International Conference on Information Fusion, Institute of Electrical and Electronics Engineers (IEEE)*. IEEE conference proceedings 2016 ISBN 978-0-9964527-4-8. P.1894-1900

Fortuna, Joao; Martens, Harald. Multivariate Data Modelling for De-shadowing of Airborne Hyperspectral Imaging. *IASIM-2016, 6th International Conference in Spectral Imaging*; 2016-07-03 - 2016-07-06

Fossen, Thor I. Nonlinear Observer Design for Strapdown Inertial Navigation Systems. *10th IFAC Symposium on Nonlinear Control System (NOLCOS´16)*; 2016-08-23 - 2016-08-25

Fossum, Trygve Olav; Ludvigsen, Martin; Nornes, Stein Melvær; Rist-Christensen, Ida; Sletbakk Brusletto, Lars. Autonomous Robotic Intervention Using ROV: An Experimental Approach. IN: *OCEANS 2016 MTS/IEEE Monterey*. IEEE conference proceedings 2016 ISBN 978-1-5090-1537-5.

Fucile, Fabio; Ludeno, Giovanni; Serafino, Francesco; Bulian, Gabriele; Soldovieri, Francesco; Lugni, Claudio. Some challenges in recovering wave features from a wave radar system. *ISOPE - International Offshore and Polar Engineering Conference. Proceedings* 2016 ;Volume 2016-January. P.319-326

Fusini, Lorenzo; Johansen, Tor Arne; Fossen, Thor I. A globally exponentially stable non-linear velocity observer for vision-aided UAV dead reckoning. IN: *2016 IEEE Aerospace Conference (AERO2016)*. IEEE conference proceedings 2016 ISBN 9781467376778.

Grancharova, Alexandra; Johansen, Tor Arne; Petrova, Valeria. Distributed Nonlinear Model Predictive Control by Sequential Linearization and Accelerated Gradient Method. *IFAC-PapersOnLine* 2016 ;Volume 49.(7) P.597-602

Grøtli, Esten Ingar; Tjønnås, Johannes; Azpiazu Lozano, Jon; Transeth, Aksel Andreas; Ludvigsen, Martin. Towards more autonomous ROV operations: Scalable and modular localization with experiment data. *IFAC-PapersOnLine* 2016 ;Volume 49.(23) P.173-180

Hansen, Jakob Mahler; Johansen, Tor Arne; Fossen, Thor I. Tightly coupled integrated inertial and real-time-kinematic positioning approach using nonlinear observer. *American Control Conference (ACC)* 2016 ;Volume 2016-July. P.5511-5518

Hasan, Agus Ismail; Imsland, Lars Struen; Ivanov, Ivan; Kostova, Snezhana; Bogdanova, Boryana. Optimal Boundary Control of 2×2 Linear Hyperbolic PDEs. IN: *24th Mediterranean Conference on Control and Automation (MED)*. IEEE conference proceedings 2016 ISBN 978-1-4673-8345-5. P.164-169

Hassani, Vahid; Rindarøy, Martin; Kyllingstad, Lars Tandle; Nielsen, Jørgen Bremnes; Sadjina, Severin Simon; Skjong, Stian; Fathi, Dariusz Eirik; Johnsen, Trond Andreas Vikan; Æsøy, Vilmar; Pedersen, Eilif. Virtual prototyping of maritime systems and operations. IN: *ASME 2016 35th International Conference on Ocean, Offshore and Arctic Engineering - Volume 7: Ocean Engineering*. ASME Press 2016 ISBN 978-0-7918-4998-9.

Helgesen, Håkon Hagen; Leira, Frederik Stendahl; Johansen, Tor Arne; Fossen, Thor I. Tracking of Marine Surface Objects from Unmanned Aerial Vehicles with a Pan/Tilt Unit using a Thermal Camera and Optical Flow. IN: *2016 International Conference on Unmanned Aircraft Systems (ICUAS)*. IEEE conference proceedings 2016 ISBN 978-1-4673-9334-8.

Henriksen, Eirik Hexeberg; Schjølberg, Ingrid; Gjersvik, Tor Berge. UW MORSE - The UnderWater Modular Open Robot Simulation Engine. *IEEE / OES Autonomous Underwater Vehicles. Proceedings* 2016 P.261-267

Henriksen, Eirik Hexeberg; Schjølberg, Ingrid; Gjersvik, Tor Berge Stray. Adaptable Joystick Control System for Underwater Remotely Operated Vehicles. *IFAC-PapersOnLine* 2016 ;Volume 49.(23) P.167-172

Henriksen, Vegard Wie; Røine, Audun Gerhardsen; Skjong, Espen; Johansen, Tor Arne. Three-axis Motion Compensated Crane Head Control. *IFAC-PapersOnLine* 2016 ;Volume 49.(23) P.159-166

Heyn, Hans-Martin; Skjetne, Roger. A System for Measuring Ice-Induced Accelerations and Identifying Ice Actions on the CCGS Amundsen and a Swedish Atle-Class Icebreaker. IN: *ASME 2016 35th International Conference on Ocean, Offshore and Arctic Engineering - Volume 8: Polar and Arctic Sciences and Technology; Petroleum Technology*. ASME Press 2016 ISBN 978-0-7918-4999-6. P.V008T07A025

Horn, Jan-Tore H.; Jensen, Jørgen Juncher. Reducing uncertainty of Monte Carlo estimated fatigue damage in offshore wind turbines using FORM. IN: *Proceedings of the 13th International Symposium on PRActical Design of Ships and Other Floating Structures (PRADS' 2016)*. Danmarks Tekniske Universitet, DTU 2016 ISBN 978-87-7475-473-2.

Hosen, Jesper; Helgesen, Håkon Hagen; Fusini, Lorenzo; Fossen, Thor I.; Johansen, Tor Arne. A vision-aided nonlinear observer for fixed-wing UAV navigation. IN: *AIAA Guidance, Navigation, and Control Conference 2016.* American Institue of Aeronautics and Astronautics 2016 ISBN 978-162410389-6.

Johansen, Tor Arne; Brekke, Edmund Førland. Globally Exponentially Stable Kalman Filter for SLAM with AHRS. IN: *Proceedings of the 19th International Conference on Information Fusion, Institute of Electrical and Electronics Engineers (IEEE)*. IEEE conference proceedings 2016 ISBN 978-0-9964527-4-8.

Johansen, Tor Arne; Cristofaro, Andrea; Perez, Tristan. Ship Collision Avoidance Using Scenario-Based Model Predictive Control. *Elsevier IFAC Publications / IFAC Proceedings series* 2016 ;Volume 49.(23) P.14-21

Johansen, Tor Arne; Fossen, Thor I. Nonlinear Filtering with eXogenous Kalman Filter and Double Kalman Filter. *European Control Conference*; 2016-06-29 - 2016-07-01

Johansen, Tor Arne; Perez, Tristan. Unmanned Aerial Surveillance System for Hazard Collision Avoidance in Autonomous Shipping. IN: *2016 International Conference on Unmanned Aircraft Systems (ICUAS)*. IEEE conference proceedings 2016 ISBN 978-1-4673-9334-8.

Johnsen, Geir; Ludvigsen, Martin; Sørensen, Asgeir Johan; Aas, Lars Martin Sandvik. The use of underwater hyperspectral imaging deployed on remotely operated vehicle – methods and applications. *IFAC-PapersOnLine* 2016 ;Volume 49.(23) P.476-481

Jørgensen, Erlend Kvinge; Johansen, Tor Arne; Schjølberg, Ingrid. Enhanced Hydroacoustic Range Robustness of Three-Stage Position Filter based on Long Baseline Measurements with Unknown Wave Speed. *IFAC-PapersOnLine* 2016 ;Volume 49.(23) P.61-67

Jørgensen, Erlend Kvinge; Schjølberg, Ingrid. Attitude and Gyro bias estimation using range-difference and IMU measurements. *Autonomous Underwater Vehicles (AUV), 2016 IEEE/OES* 2016 P.124-130

Jørgensen, Erlend Kvinge; Schjølberg, Ingrid. ROV End-effector Stabilization for Unknown, Time-varying Currents. *European Control Conference*; 2016-06-29 - 2016-07-01

Kelasidi, Eleni; Kohl, Anna Magdalena; Pettersen, Kristin Ytterstad; Gravdahl, Jan Tommy. Waypoint guidance control for underwater snake robots exposed to ocean currents. IN: *24th Mediterranean Conference on Control and Automation (MED)*. IEEE conference proceedings 2016 ISBN 978-1-4673-8345-5. P.518-525

Kelasidi, Eleni; Pettersen, Kristin Ytterstad; Liljebäck, Pål; Gravdahl, Jan Tommy. Locomotion Efficiency of Underwater Snake Robots with Thrusters. IN: *International Symposium on Safety, Security and Rescue Robotics*. IEEE conference proceedings 2016 ISBN 978-1-5090-4349-1.

Kim, Ekaterina; Song, Ming; Amdahl, Jørgen. On ice model validation and calibration strategies for damage as-sessment of structures subjected to impact actions. IN: *7th International Conference on Collision and Grounding of Ships and Offshore Structures (ICCGS 2016)*. 2016 ISBN 9788995001639. P.149-156

Kjerstad, Øivind Kåre; Værnø, Svenn Are Tutturen; Skjetne, Roger. A Robust Dynamic Positioning Tracking Control Law Mitigating Integral Windup. *IFAC-PapersOnLine* 2016 ;Volume 49.(23) P.239-244

Klausen, Kristian; Moe, Jostein Borgen; van der Horn, Jornel; Gomola, Alojz; Fossen, Thor I.; Johansen, Tor Arne. Coordinated Control Concept for Recovery of a Fixed-Wing UAV on a Ship using a Net Carried by Multirotor UAVs. IN: *2016 International Conference on Unmanned Aircraft Systems (ICUAS)*. IEEE conference proceedings 2016 ISBN 978-1-4673-9334-8.

Kufoalor, D. Kwame Minde; Imsland, Lars Struen; Johansen, Tor Arne. Efficient Quadratic Programming Frameworks for Industrial Embedded Model Predictive Control. *European Control Conference, ECC 2016*; 2016-06-29 - 2016-07-01

Lader, Pål; Fredriksson, David W.; Volent, Zsolt; DeCew, Jud; Rosten, Trond Waldemar; Strand, Ida Marlen. Wave Response of Closed Flexible Bags. IN: *ASME 2016 35th International Conference on Ocean, Offshore and Arctic Engineering - Volume 6: Ocean Space Utilization; Ocean Renewable Energy*. ASME Press 2016 ISBN 978-0-7918-4997-2.

Lekkas, Anastasios M.; Roald, Ann Louise; Breivik, Morten. Online Path Planning for Surface Vehicles Exposed to Unknown Ocean Currents Using Pseudospectral Optimal Control. *IFAC-PapersOnLine* 2016 ;Volume 49.(23) P.1-7

Lu, Wenjun; Lubbad, Raed; Løset, Sveinung; Skjetne, Roger. Parallel Channel Tests during Ice Management Operations in the Arctic Ocean. IN: *Arctic Technology Conference 2016 (Proceedings)*. 2016 ISBN 978-1-61399-489-4.

Lu, Wenjun; Zhang, Qin; Lubbad, Raed; Løset, Sveinung; Skjetne, Roger. A Shipborne Measurement System to Acquire Sea Ice

Thickness and Concentration at Engineering Scale. IN: *Arctic Technology Conference 2016 (Proceedings)*. 2016 ISBN 978-1-61399-489-4.

Luan, Chenyu; Gao, Zhen; Moan, Torgeir. Design and Analysis of a Braceless Steel 5-MW Semi-Submersible Wind Turbine. IN: *ASME 2016 35th International Conference on Ocean, Offshore and Arctic Engineering - Volume 6: Ocean Space Utilization; Ocean Renewable Energy*. ASME Press 2016 ISBN 978-0-7918-4997-2.

Ludvigsen, Martin; Albrektsen, Sigurd Mørkved; Cisek, Krzysztof; Johansen, Tor Arne; Norgren, Petter; Skjetne, Roger; Zolich, Artur Piotr; Dias, Paulo Sousa; ferreira, sergio; Sousa, Joao Borges; Fossum, Trygve Olav; Sture, Øyvind; Krogstad, Thomas Røbekk; Midtgaard, Øivind; Hovstein, Vegard Evjen; Vågsholm, Erlend. Network of heterogeneous autonomous vehicles for marine research and management. IN: *OCEANS 2016 MTS/IEEE Monterey*. IEEE conference proceedings 2016 ISBN 978-1-5090-1537-5.

Mathisen, Siri Holthe; Gryte, Kristoffer; Johansen, Tor Arne; Fossen, Thor I. Non-linear Model Predictive Control for Longitudinal and Lateral Guidance of a Small Fixed-Wing UAV in Precision Deep Stall Landing. IN: *AIAA Infotech at Aerospace 2016*. 2016 ISBN 978-1-62410-388-9.

Merz, Mariann; Johansen, Tor Arne. Feasibility study of a circularly towed cable-body system for UAV applications. IN: *2016 International Conference on Unmanned Aircraft Systems (ICUAS)*. IEEE conference proceedings 2016 ISBN 978-1-4673-9334-8. P.1182-1191

Michailides, Constantine; Gao, Zhen; Moan, Torgeir. A sensitivity study of wave and wind induced responses of the combined energy concept SFC based on experimental measurements. *ISOPE - International Offshore and Polar Engineering Conference. Proceedings* 2016 ;Volume 2016-January. P.537-544

Moan, Torgeir. Life Cycle Structural Integrity Management of Offshore Steel Structures. IN: *Life-Cycle of Engineering Systems: Emphasis on Sustainable Civil Infrastructure: Proceedings of the Fifth International Symposium on Life-Cycle Civil Engineering (ILCCE 2016)*. CRC Press 2016 ISBN 9781138028470. P.33-39

Moe, Signe; Pettersen, Kristin Ytterstad; Fossen, Thor I.; Gravdahl, Jan Tommy. Line-of-Sight Curved Path Following for Underactuated USVs and AUVs in the Horizontal Plane under the influence of Ocean Currents. *IEEE Mediterranean Conference on Control & Automation* 2016

Moe, Signe; Pettersen, Kristin Ytterstad. Set-Based Line-of-Sight (LOS) Path Following with Collision Avoidance for Underactuated Unmanned Surface Vessel. *IEEE Mediterranean Conference on Control & Automation* 2016

Moe, Signe; Teel, Andrew R; Antonelli, Gianluca; Pettersen, Kristin Ytterstad. Stability analysis for set-based control within the singularity-robust multiple task-priority inverse kinematics framework. *I E E E Conference on Decision and Control. Proceedings* 2016 ;Volume 2016-February. P.171-178

Montazeri, Najmeh; Nielsen, Ulrik Dam; Jensen, Jørgen Juncher. Selection of the optimum combination of responses for Wave Buoy Analogy - An approach based on local sensitivity analysis. IN: *Proceedings of the 13th International Symposium on PRActical Design of Ships and Other Floating Structures (PRADS' 2016)*. Danmarks Tekniske Universitet, DTU 2016 ISBN 978-87-7475-473-2.

Nam, Woongshik; Amdahl, Jørgen; Hopperstad, Odd Sture. Influence of brittle fracture on the crashworthiness of ship and offshore structures in Arctic conditions. IN: *7th International Conference on Collision and Grounding of Ships and Offshore Structures (ICCGS 2016)*. 2016 ISBN 9788995001639. P.63-68

Nielsen, Mikkel Cornelius; Blanke, Mogens; Schjølberg, Ingrid. Efficient Modelling Methodology for Reconfigurable Underwater Robots. *IFAC-PapersOnLine* 2016 ;Volume 49.(23) P.74-80

Nielsen, Mikkel Cornelius; Eidsvik, Ole Alexander; Blanke, Mogens; Schjølberg, Ingrid. Validation of multi-body modelling methodology for reconfigurable underwater robots. IN: *OCEANS 2016 MTS/IEEE Monterey*. IEEE conference proceedings 2016 ISBN 978-1-5090-1537-5.

Nielsen, Ulrik Dam; Galeazzi, Roberto; Brodtkorb, Astrid H. Evaluation of Shipboard Wave Estimation Techniques Through Model-scale Experiments. IN: *OCEANS 2016 Shanghai - MTS/IEEE*. IEEE conference proceedings 2016 ISBN 978-1-4673-9723-0.

Nornes, Stein Melvær; Ludvigsen, Martin; Sørensen, Asgeir Johan. Automatic Relative Motion Control and Photogrammetry Mapping on Steep Underwater Walls using ROV. IN: *OCEANS 2016 MTS/IEEE Monterey*. IEEE conference proceedings 2016 ISBN 978-1-5090-1537-5.

Ommani, Babak; Fonseca, Nuno; Kristiansen, Trygve; Bakksjø, Hanne. Bilge keel induced roll damping of an FPSO with sponsons. IN: *ASME 2016 35th International Conference on Ocean, Offshore and Arctic Engineering Volume 1: Offshore Technology; Offshore Geotechnics*. ASME Press 2016 ISBN 978-0-7918-4992-7.

Osterloff, Jonas; Nilssen, Ingunn; Nattkemper, Tim W. Computational coral feature monitoring for the fixed underwater observatory LoVe. IN: *OCEANS 2016 MTS/IEEE Monterey*. IEEE conference proceedings 2016 ISBN 978-1-5090-1537-5.

Paliotta, Claudio; Pettersen, Kristin Ytterstad. Leader-follower synchronization with disturbance rejection. IN: *2016 IEEE Conference on Control Applications*. IEEE conference proceedings 2016 ISBN 978-1-5090-0754-7. P.360-367

Paliotta, Claudio; Pettersen, Kristin Ytterstad. Geometric path following with ocean current estimation for ASVs and AUVs. *American Control Conference (ACC)* 2016 ;Volume 2016- July. P.7261-7268

Py, Frederic; Pinto, J; Silva, MA; Johansen, Tor Arne; Sousa, Joao Borges de; Rajan, Kanna. EUROPtus: A mixed-initiative controller for multi-vehicle oceanographic field experiments. *Int. Symp. Experimental Robotics (ISER)*; 2016-10-03 - 2016-10-06

Rabanal, Ole Maurice Røste; Brodtkorb, Astrid H.; Breivik, Morten. Comparing Controllers for Dynamic Positioning of Ships in Extreme Seas. *IFAC-PapersOnLine* 2016 ;Volume 49.(23) P.258-264

Rejani Miyazaki, Michel; Sørensen, Asgeir Johan; Vartdal, Bjørn J. Hybrid marine power plants model validation with strategic loading. *Elsevier IFAC Publications / IFAC Proceedings series* 2016 ;Volume 49.(23) P.400-407

Ren, Zhengru; Skjetne, Roger. A Tension-based Position Estimation Solution of a Moored Structure and its Uncertain Anchor Positions. *IFAC-PapersOnLine* 2016 ;Volume 49.(23) P.251-257

Ren, Zhengru; Skjetne, Roger. An On-site Current Profile Estimation Algorithm for a Moored Floating Structure. *IFAC-PapersOnLine* 2016 ;Volume 49.(23) P.153-158

Rogne, Robert Harald; Bryne, Torleiv Håland; Fossen, Thor I.; Johansen, Tor Arne. Fault Detection in Lever-arm-compensated Position Reference Systems based on Nonlinear Attitude Observers and Inertial Measurements in Dynamic Positioning. *American Control Conference (ACC)*; 2016-07-06 - 2016-07-08

Rogne, Robert Harald; Bryne, Torleiv Håland; Fossen, Thor I.; Johansen, Tor Arne. MEMS-based Inertial Navigation on Dynamically Positioned Ships: Dead Reckoning. *Elsevier IFAC Publications / IFAC Proceedings series* 2016 ;Volume 49.(23) P.139-146

Rotondo, Damiano; Cristofaro, Andrea; Johansen, Tor Arne; Nejjari, Fatiha; Puig, Vicenç. Detection of icing and actuators faults in the longitudinal dynamics of small UAVs using an LPV proportional integral unknown input observer. *3rd Conference on Control and Fault-Tolerant Systems (SysTol)*; 2016-09-07 - 2016-09-09

Rotondo, Damiano; Ponsart, Jean-Christophe; Nejjari, Fatiha; Theilliol, Didier; Puig, Vicenç. Virtual actuator-based FTC for LPV systems with saturating actuators and FDI delays. *3rd Conference on Control and Fault-Tolerant Systems (SysTol)*; 2016-09-07 - 2016-09-09

Sanfilippo, Filippo; Azpiazu, Jon; Marafioti, Giancarlo; Transeth, Aksel Andreas; Stavdahl, Øyvind; Liljebäck, Pål. A Review on Perception-driven Obstacle-aided Locomotion for Snake Robots. IN: *Proceeding of the 14th IEEE International Conference on Control, Automation, Robotics and Vision (ICARCV)*. IEEE conference proceedings 2016 ISBN 978-1-5090-4757-4.

Sanfilippo, Filippo; Stavdahl, Øyvind; Marafioti, Giancarlo; Transeth, Aksel Andreas; Liljebäck, Pål. Virtual Functional Segmentation of Snake Robots for Perception-Driven Obstacle-Aided Locomotion. IN: *Proceeding of the IEEE Conference on Robotics and Biomimetics (ROBIO 2016)*. IEEE conference proceedings 2016 ISBN 978-1-5090-4363-7. P.1845-1851

Sans Muntadas, Albert; Pettersen, Kristin Ytterstad; Brekke, Edmund Førland. Vision Restricted Path Planning and Control for Underactuated Vehicles. *Elsevier IFAC Publications / IFAC Proceedings series* 2016 ;Volume 49.(23) P.199-206

Sans-Muntadas, Albert; Pettersen, Kristin Ytterstad; Brekke, Edmund Førland; Henriksen, Vegard F. A hybrid approach to underwater docking of AUVs with cross-current. *OCEANS* 2016

Sauder, Thomas Michel; Chabaud, Valentin Bruno; Thys, Maxime; Bachynski, Erin Elizabeth; Sæther, Lars Ove. Real-time hybrid model testing of a braceless semi-submersible wind turbine. Part I: The hybrid approach. IN: *ASME 2016 35th International Conference on Ocean, Offshore and Arctic Engineering - Volume 6: Ocean Space Utilization; Ocean Renewable Energy*. ASME Press 2016 ISBN 978-0-7918-4997-2.

Schjølberg, Ingrid; Gjersvik, Tor Berge Stray; Transeth, Aksel Andreas; Utne, Ingrid Bouwer. Next Generation Subsea Inspection, Maintenance and Repair Operations. *IFAC-PapersOnLine* 2016 ;Volume 49.(23) P.434-439

Sha, Yanyan; Amdahl, Jørgen. Design of floating bridge girders against accidental ship collision loads. IN: *19th Congress of IABSE, Challenges in Design and Construction of an Innovative and Sustainable Built Environment*. International Association for Bridge and Structural Engineering 2016 ISBN 978-3-85748-144-4. P.1919-1926

Sha, Yanyan; Amdahl, Jørgen. Design of Floating Bridge Pontoon subjected to Ship Collision. IN: *7th International Conference on Collision and Grounding of Ships and Offshore Structures (ICCGS 2016)*. 2016 ISBN 9788995001639. P.263-269

Shen, Yugao; Greco, Marilena; Faltinsen, Odd Magnus. Numerical study of a coupled well boat-fish farm system in waves and current during loading operations. *12th International Conference on Hydrodynamics*; 2016-09-18 - 2016-09-23

Skjong, Espen; Gale, Serge; Molinas Cabrera, Maria Marta; Johansen, Tor Arne. Data-Driven decision support tool for power quality measures in marine vessel power system. IN: *2016 IEEE Transportation Electrification Conference and Expo (ITEC)*. IEEE conference proceedings 2016 ISBN 978-1-5090-0403-4.

Smilden, Emil; Horn, Jan-Tore H.; Sørensen, Asgeir Johan; Amdahl, Jørgen. Reduced Order Model for Control Applications in Offshore Wind Turbines. *IFAC-PapersOnLine* 2016 ;Volume 49.(23) P.386-393

Smilden, Emil; Sørensen, Asgeir Johan. Application of a Speed Exclusion Zone Algorithm on a Large 10MW Offshore Wind Turbine. IN: *ASME 2016 35th International Conference on Ocean, Offshore and Arctic Engineering - Volume 6: Ocean Space Utilization; Ocean Renewable Energy*. ASME Press 2016 ISBN 978-0-7918-4997-2.

Song, Ming; Kim, Ekaterina; Amdahl, Jørgen; Greco, Marilena; Souli, M'Hamed. Numerical Investigation of Fluid-Ice-Structure Interaction During Collision by an Arbitrary Lagrangian Eulerian Method. IN: *ASME 2016 35th International Conference on Ocean, Offshore and Arctic Engineering - Volume 8: Polar and Arctic Sciences and Technology; Petroleum Technology*. ASME Press 2016 ISBN 978-0-7918-4999-6.

Sousa, Joao Borges de; Rajan, Kanna; Pereira, J.; Pinto, J; Lourenco, PC; Galocha, JM; Fontes, Jorge; Johansen, Tor Arne; Incze, M; Alves, J; Pelekanakis, K; Munafo, A; Petroccia, R. Rapid Environmental Picture Atlantic exercise 2015: a field report. IN: *OCEANS 2016 MTS/IEEE Monterey*. IEEE conference proceedings 2016 ISBN 978-1-5090-1537-5.

Storheim, Martin; Amdahl, Jørgen; Notaro, Gabriele; Johansen, Atle. Comparison of ABAQUS and LS-DYNA in simulations of ship collisions. IN: *7th International Conference on Collision and Grounding of Ships and Offshore Structures (ICCGS 2016)*. 2016 ISBN 9788995001639. P.239-246

Stovner, Bård Bakken; Johansen, Tor Arne; Fossen, Thor I.; Schjølberg, Ingrid. Three-stage filter for position and velocity estimation from long baseline measurements with unknown wave speed. *American Control Conference (ACC)* 2016 P.4532-4538

Sverdrup-Thygeson, Jørgen; Kelasidi, Eleni; Pettersen, Kristin Ytterstad; Gravdahl, Jan Tommy. A control framework for biologically inspired underwater swimming manipulators equipped with thrusters. *Elsevier IFAC Publications / IFAC Proceedings series* 2016 ;Volume 49.(23) P.89-96

Sverdrup-Thygeson, Jørgen; Kelasidi, Eleni; Pettersen, Kristin Ytterstad; Gravdahl, Jan Tommy. Modeling of underwater swimming manipulators. *Elsevier IFAC Publications / IFAC Proceedings series* 2016 ;Volume 49.(23) P.81-88

Sverdrup-Thygeson, Jørgen; Kelasidi, Eleni; Pettersen, Kristin Ytterstad; Gravdahl, Jan Tommy. The Underwater Swimming Manipulator - A Bio-Inspired AUV. IN: *Autonomous Underwater Vehicles (AUV), 2016 IEEE/OES*. IEEE conference proceedings 2016 ISBN 978-1-5090-2442-1. P.387-395

Syre Wiig, Martin; Caharija, Walter; Krogstad, Thomas Røbekk; Pettersen, Kristin Ytterstad. Integral Line-of-Sight Guidance of Underwater Vehicles Without Neutral Buoyancy. *IFAC-PapersOnLine* 2016 ;Volume 49.(23) P.590-597

Sørensen, Kim Lynge; Johansen, Tor Arne. Thermodynamics of a carbon nano-materials based icing protection system for unmanned aerial vehicle. IN: *2016 IEEE Aerospace Confe—rence (AERO 2016)*. IEEE conference proceedings 2016 ISBN 9781467376778.

Sørensen, Mikkel Eske Nørgaard; Bjørne, Elias; Breivik, Morten. Performance Comparison of Backstepping-Based Adaptive Controllers for Marine Surface Vessels. IN: *Proceedings of 2016 IEEE Conference on Control Applications (CCA)*. IEEE conference proceedings 2016 ISBN 978-150900755-4.

Sørensen, Mikkel Eske Nørgaard; Breivik, Morten. Comparing Combinations of Linear and Nonlinear Feedback Terms for Motion Control of Marine Surface Vessels. *IFAC-PapersOnLine* 2016 ;Volume 49.(23) P.303-310

Tyushev, Kirill; Amelin, Konstantin; Andrievsky, Boris; Shiriaev, Anton. The method of saving data integrity for decentralized network of group of UAV using quantized gossip algorithms. *IFAC-PapersOnLine* 2016 ;Volume 49.(13) P.259-264

Vagia, Marialena; Eielsen, Arnfinn Aas; Gravdahl, Jan Tommy; Pettersen, Kristin Ytterstad. Nonlinear Tracking Control Scheme for a Nanopositioner. *Mediterranean Conference on Control and Automation* 2016

Vamråk, Vegard; Bua, Nils Haktor; Hassani, Vahid; Auestad, Øyvind Fidje. Robust Lateral Control of a Surface Effect Ship using H Mixed Sensitivity Synthesis. *IFAC-PapersOnLine* 2016 ;Volume 49.(23) P.540-545

Værnø, Svenn Are Tutturen; Brodtkorb, Astrid H.; Skjetne, Roger; Sørensen, Asgeir Johan. An Output Feedback Controller with Improved Transient Response of Marine Vessels in Dynamic Positioning. *IFAC-PapersOnLine* 2016 ;Volume 49.(23) P.133-138

Wan, Ling; Gao, Zhen; Moan, Torgeir. Nonlinear local structural modelling and analysis of the interface for a hybrid wind and wave energy converter concept. *ISOPE – International Offshore and Polar Engineering Conference. Proceedings* 2016 ;Volume 2016-January. P.553-561

Wenz, Andreas Wolfgang; Johansen, Tor Arne; Cristofaro, Andrea. Combining model-free and model-based angle of attack estimation for small fixed-wing UAVs using a standard sensor suite. IN: *2016 International Conference on Unmanned Aircraft Systems (ICUAS)*. IEEE conference proceedings 2016 ISBN 978-1-4673-9334-8. P.624-632

Wilthil, Erik Falmår; Brekke, Edmund Førland. Compensation of navigation uncertainty for target tracking on a moving platform. IN: *Proceedings of the 19th International Conference on Information Fusion, Institute of Electrical and Electronics Engineers (IEEE)*. IEEE conference proceedings 2016 ISBN 978-0-9964527-4-8. P.1616-1621

Xidias, Elias K.; Paliotta, Claudio; Aspragathos, Nikos A.; Pettersen, Kristin Ytterstad. Path Planning for Formation Control of Autonomous Vehicles. IN: *Advances in Robot Design and Intelligent Control*. Springer 2016 ISBN 978-3-319-49058-8. P.302-309

Yu, Zhaolong; Amdahl, Jørgen. Influence of 6DOF ship motions in the damage prediction of ship collision and grounding accidents. IN: *7th International Conference on Collision and Grounding of Ships and Offshore Structures (ICCGS 2016)*. 2016 ISBN 9788995001639. P.199-205

Zolich, Artur Piotr; Alfredsen, Jo Arve; Johansen, Tor Arne; Skøien, Kristoffer Rist. A communication bridge between underwater sensors and unmanned vehicles using a surface wireless sensor network - design and validation. IN: *OCEANS 2016 Shanghai - MTS/IEEE*. IEEE conference proceedings 2016 ISBN 978-1-4673-9723-0. P.1-9

Ødegård, Øyvind; Nornes, Stein Melvær; Ludvigsen, Martin; Maarleveld, Thijs J.; Sørensen, Asgeir Johan. Autonomy in Marine Archaeology. IN: *Proceedings of the 43rd Annual Conference on Computer Applications and Quantitative Methods in Archaeology*. Archaeopress 2016 ISBN 9781784913380. P.857-865

Ødegård, Øyvind; Sørensen, Asgeir Johan; Hansen, Roy Edgar; Ludvigsen, Martin. A new method for underwater archaeological surveying using sensors and unmanned platforms. *Elsevier IFAC Publications / IFAC Proceedings series* 2016 ;Volume 49.(23) P.486-493

Keynote lectures

Faltinsen, Odd Magnus. Hydrodynamics of fish farms and marine animals. *12th International Conference on Hydrodynamics, ICHD2016; 2016-09-18 - 2016-09-23*

Faltinsen, Odd Magnus. Modelling of manoeuvring in calm water and waves. *2nd International Meeting on Recent Advances in Prediction Techniques for Safe Manoeuvring of Ships and Submarines;* 2016-11-17 - 2016-11-18

Faltinsen, Odd Magnus. Sloshing. *The 24th Wallace Lecture in Ocean Sciences and Engineering;* 2016-04-01 - 2016-04-01

Faltinsen, Odd Magnus. Sloshing induced loads. *Offshore Korea Technical Conference 2016 (OK Conference 2016);* 2016-10-19 - 2016-10-21

Fossen, Thor I. Nonlinear Observer Design for Strapdown Inertial Navigation Systems. *10th IFAC Symposium on Nonlinear Control System (NOLCOS´16);* 2016-08-23 - 2016-08-25

Moan, Torgeir; Amdahl, Jørgen; Ersdal, Gerhard. Assessment of ship impact risk to offshore structures - new NORSOK N-003 guidelines. *The 3rd Offshore Structural Reliability Conference OSRC2016;* 2016-09-14 - 2016-09-16

Moan, Torgeir. Life Cycle Structural Integrity Management of Offshore Structures. *5th International Symposium on Life-cycle Civil Engineering;* 2016-10-16 - 2016-10-19

Pettersen, Kristin Ytterstad. Swimming snake robots – a bio-inspired solution for subsea inspection and intervention. *IEEE International Symposium on Safety, Security, and Rescue Robotics (SSRR);* 2016-10-23 - 2016-10-27

Sørensen, Asgeir Johan. Marine Cybernetics: Enabling autonomous marine operations and systems. *SOBENA Conference -The Brazilian Society of Naval Architecture, Marine and Offshore Engineering Conference (SOBENA);* 2016-11-08 - 2016-11-10

Sørensen, Asgeir Johan. Towards Safer, Smarter and Greener Marine Operations and Systems. *13th International Symposium on Practical Design of Ships and Other Floating Structures (PRADS'2016);* 2016-09-04 - 2016-09-08

Media coverage

Aasly, Kurt; Ellefmo, Steinar Løve; Ludvigsen, Martin. På skattejakt til Jan Mayen. *Under Dusken* No. 7, 2016 [Journal] 2016-04-19

Bakka, Haakon Christopher; Toraskar, Jimita Prashant; Platou, Rikke Stoud; Schultz, Joseph Samuel; Snipstad, Sofie; Aurand, Katherine Rose; Lehmann O, Olga V; Finnøy, Andreas; Mathisen, Siri Holthe. Forsker Grand Prix 2016, regionfinale i Trondheim. *NRK* [TV] 2016-09-29

Berge, Jørgen. Da forskerne dro opp tømmerstokken, ble de skremt av det de fant. *Nettavisen* [Newspaper] 2016-02-27

Berge, Jørgen. Månesykt plankton. *NRK P2 Ekko* [Radio] 2016-02-08

Berge, Jørgen. Spiser opp vrak på havbunnen. *Forskning.no* [Internet] 2016-02-29

Berge, Jørgen; Falk-Petersen, Stig; Renaud, Paul E.; Daase, Malin; Geoffroy, Maxime; Johnsen, Geir. En reise mot Ultima Thule. *Svalbardposten* 2016

Berge, Jørgen; Johnsen, Geir. Meet the Night Creatures of the Warming Arctic. *Audobon Magazine* [Journal] 2016-01-01

Berge, Jørgen; Johnsen, Geir. Mørkets fyrster med påskrudd lys. *Svalbardposten* 2016 ;Volume 4. P.20-20

Berge, Jørgen; Johnsen, Geir; Ludvigsen, Martin; Cohen, Jonathan. Design for latskap - men med store muligheter. *Svalbardposten* 2016 (5)

Berge, Jørgen; Johnsen, Geir; Malzahn, Nicole; Cohen, Jonathan. Floating in the Arctic Darkness. *The Atlantic* [Journal] 2016-03-22

Berge, Jørgen; Johnsen, Geir; Sørensen, Asgeir Johan. Et stort løft for arktisk forskning (NTNU & UiT). *Universitetet i Tromsø* 2016

Berge, Jørgen; Johnsen, Geir; Ødegård, Øyvind. Kinderegg i polarnatten. *Svalbardposten* 2016

Berge, Jørgen; Johnsen, Geir; Ødegård, Øyvind. Mark spiser opp vrak på havbunnen. *FiskeribladetFiskaren* [Newspaper] 2016-02-28

Berge, Jørgen; Johnsen, Geir; Ødegård, Øyvind. Skrekklarven var båtfolkets mareritt. *Dagbladet* 2016

Berge, Jørgen; Johnsen, Geir; Ødegård, Øyvind. The age of humans - living in the anthropocene - "Termites of the sea" found munching wood near Arctic shipwrecks. *Smithsonian* 2016

Berge, Jørgen; Last, Kim; Cohen, Jonathan; Johnsen, Geir. Voyage into darkness. *Science* 2016 ;Volume 351.(6279) P.1254-1257

Berge, Jørgen; Renaud, Paul E.; Johnsen, Geir; Darnis, Gerald; Geoffroy, Maxime; Daase, Malin; Kwasniewski, S; Draganska, K; Cottier, Finlo Robert; Falk-Petersen, Stig. I grenselandet (mellom Tull og Thule). *Svalbardposten* 2016

Berge, Jørgen; Ødegård, Øyvind; Johnsen, Geir. A bitter-sweet symphony. *Svalbardposten* 2016

Berge, Jørgen; Ødegård, Øyvind; Johnsen, Geir. Arctic shipworm discovery alarms archaeologists. *Science* [Journal] 2016-02-26

Berge, Jørgen; Ødegård, Øyvind; Johnsen, Geir. Opp fra polarnattens mørke. *Aftenposten Viten* 2016

Breivik, Morten. Slutten for den norske sjømann. *Bergens Tidende* [Newspaper] 2016-11-07

Breivik, Morten. University Students and Researchers Test Own Control Algorithms on Industrial DP System Platform. *Kongsberg Maritime* [Internet] 2016-11-25

Breivik, Morten; Skjetne, Roger. Tester ut elektronisk anker på eget forskningsfartøy. *Gemini* [Internet] 2016-11-28

Eirik, Palm; Berge, Jørgen; Johnsen, Geir. Fant dypvannsfisk på grunna. *Svalbardposten* [Newspaper] 2016-01-29

Erdal, Ivar; Johnsen, Geir. Kameraet deres «kan bli det nye ekkoloddet». Nå er det norske selskapet i ferd med å lykkes. *Teknisk Ukeblad* 2016

Erdal, Ivar; Johnsen, Geir; Sørensen, Asgeir Johan; Fjærvik, Nils. Gründerne mener dette kameraet kan bli det nye ekkoloddet – Ecotone er kandidat til TU Tech Award. *Teknisk Ukeblad* 2016

Fossen, Thor I. People in Control. *Control Systems Magazine* 2016 ;Volum 36.(3) s. 21-24

Fredheim, Arne; Ellingsen, Harald. Skal bli kvitt lakselusa med gigantmerd. *NRK* [Internet] 2016-10-09

Fredriksen, Arnt Gunvald. Norsk ingeniør hedret i internasjonal konkurranse. *Teknisk Ukeblad* [Journal] 2016-06-03

Johnsen, Geir. God morgen Trøndelag - Polarnatt. *NRK P1* [Radio] 2016-02-23

Johnsen, Geir. Kings Bay 100 år. *NRK* [TV] 2016-12-20

Johnsen, Geir. Liv i Polarnatta. *NRK P1* [Radio] 2016-02-29

Johnsen, Geir. Nye arter funnet på Svalbard. *NRK P1* [Radio] 2016-02-23

Johnsen, Geir. Yrende liv i Isfjorden. *Svalbardposten* 2016

Johnsen, Geir; Berge, Jørgen. Fant yrende liv i polarnatta. *VG : Verdens gang* 2016

Johnsen, Geir; Berge, Jørgen; Ludvigsen, Martin; Sørensen, Asgeir Johan; Ødegård, Øyvind. Mørkets fyrster, varulver og Indiana Jones. *Gemini* 2016

Johnsen, Geir; Berge, Jørgen; Sørensen, Asgeir Johan. Dark lords, werewolves and Indiana Jones in the polar night. *Gemini (English edition)* 2016

Johnsen, Geir; Berge, Jørgen; Sørensen, Asgeir Johan; Sørumgård, Marit; Sandbakk, Elin; Johnsen, Tobias Kvendseth. Polarnatt/Polar Night - ny utstilling med nyheter fra 2015-2016. [Artistic or museum-related presentation] *Polarnatts-utstilling ved Vitenskapsmuseet NTNU*. VM NTNU; VM NTNU. 2016-09-22 - 2017-05-31

Johnsen, Geir; Kjeken, Jon; Ludvigsen, Martin. Fant buss på 600 m dybde. *Adresseavisen* 2016

Johnsen, Geir; Kjeken, John; Ludvigsen, Martin. Gammel buss ble korallrev. *NRK Viten* 2016

Johnsen, Geir; Kjeken, John; Sørensen, Asgeir Johan; Ludvigsen, Martin. Bomber og buss på havbunnen. *Gemini* 2016

Johnsen, Geir; Ludvigsen, Martin; Kjeken, John. Det ligger flere busser der. *Adresseavisen* 2016

Johnsen, Geir; Ludvigsen, Martin; Torre, Pedro De La. Vitenskab - Bomber fra 2 verdenskrig danner koralrev på 600 m dybde. *Danmarks radio* 2016

Johnsen, Geir; Sørensen, Asgeir Johan; Berge, Jørgen. Blå lys i det kalde dyp. *NRK Trøndelag, Nyheter* 2016

Johnsen, Geir; Sørensen, Asgeir Johan; Berge, Jørgen. Nye mysterier avdekkes i Polhavet. *Aftenposten* [Newspaper] 2016-01-11

Larsen, Eiliv; Anjar, Johanna; Ludvigsen, Martin; Lyså, Astrid. Vil avdekke Jan Mayens hemmeligheter. *Forskning.no* [Internet] 2016-01-05

Larsen, Eiliv; Lyså, Astrid; Ludvigsen, Martin; Anjar, Johanna. Jan Mayen-forskere fant rester av amerikansk krigsbase. *Forskning.no* [Internet] 2016-01-06

Larsen, Eiliv; Lyså, Astrid; Ludvigsen, Martin; Anjar, Johanna. The day Atlantic City blew away. *Gemini* [Internet] 2016-02-16

Liljebäck, Pål. Slangerobot inntar nye industrier. *Aftenposten - Bilag om Vitenskap* [Newspaper] 2016-04-21

Liljebäck, Pål; Pettersen, Kristin Ytterstad. Slangeroboter utfører oppdrag i havet. *Adresseavisen* [Newspaper] 2016-04-19

Liljebäck, Pål; Sørensen, Asgeir Johan. Kongsberg Maritime: Collaboration on swimming robots for subsea maintenance. *Digital Energy Journal* [Journal] 2016-05-03

Ludvigsen, Martin. Charting riches in the ocean's depths. *ScienceDaily* [Internet] 2016-10-13

Ludvigsen, Martin. Oljekrise setter fart i havroboter. *Fiskeribladet Fiskaren* [Newspaper] 2016-06-08

Ludvigsen, Martin; Aasly, Kurt; Ellefmo, Steinar Løve. Gull på havbunnen?. *Dagens næringsliv* 2016

Lyså, Astrid; Larsen, Eiliv; Ludvigsen, Martin; Anjar, Johanna. Jan Mayen's evolution through ice, fire and water. *Gemini* [Internet] 2016-02-08

Mathisen, Siri Holthe. Dronelanding som en fugl på en grein. *Radio P1, God ettermiddag Trøndelag* [Radio] 2016-10-03

Mathisen, Siri Holthe. Feltlanding med drone gir nye muligheter. *Blog*. 2016-10-10

Mathisen, Siri Holthe. Løser ligninger som styrer droner. *Gemini.no* [Internet] 2016-09-19

Nornes, Stein Melvær; Johnsen, Geir. Easier automated visual mapping of biodiversity. *Geoconnection.com* [Business/trade/industry journal] 2016-11-30

Pettersen, Kristin Ytterstad. Hun er første norske kvinne som blir IEEE fellow. *Universitetsavisa* [Newspaper] 2016-11-23

Pettersen, Kristin Ytterstad. Ærestittel for slangerobot-forsker ved NTNU. *Adresseavisen* [Newspaper] 2016-11-25

Pettersen, Kristin Ytterstad; Hovda, Asle J. Simplified Subsea Intervention with an Electric Eel. *GCE Subsea* [Internet] 2016-06-15

Pettersen, Kristin Ytterstad; Hovda, Asle J. Subsea Upcoming Company of the year. *GCE Subsea* [Internet] 2016-06-15

Pettersen, Kristin Ytterstad; Liljebäck, Pål. Slangeroboter forbedrer subsea inspeksjon og vedlikehold. *DYP - Magasinet fra Forening for Fjernstyrt Undervannsteknologi* 2016 (2) P.18-19

Pettersen, Kristin Ytterstad; Liljebäck, Pål; Jalving, Bjørn; Kvalheim, Elisabeth Birkeland. Selvgående vaktmester på havbunnen. *Adresseavisen* [Newspaper] 2016-04-18

Pettersen, Kristin Ytterstad; Liljebäck, Pål; Jalving, Bjørn; Kvalheim, Elisabeth Birkeland. Slangeroboter skal revolusjonere vedlikeholdet subsea. *Teknisk Ukeblad* [Business/trade/industry journal] 2016-04-19

Pettersen, Kristin Ytterstad; Liljebäck, Pål; Kvalheim, Elisabeth Birkeland. Slangerobot på havbunnen. *Dagsrevyen 21, NRK* [TV] 2016-06-18

Pettersen, Kristin Ytterstad; Liljebäck, Pål; Kvalheim, Elisabeth Birkeland; Schmidt, Geir Espen; Jalving, Bjørn; Sørensen, Asgeir Johan. Denne slangeroboten skal bli Statoils "vaktmester" på havbunnen. *E24* [Internet] 2016-04-18

Pettersen, Kristin Ytterstad; Ludvigsen, Martin. The shape of things to come. *Maritime Journal* [Internet] 2016-11-08

Pettersen, Kristin Ytterstad; Schmidt, Geir Espen. See snake. *Upstream Technology* [Business/trade/industry journal] 2016-06-01

Schjølberg, Ingrid. Trondheimsfjorden et utmerket testområde. *Blog*. 2016-10-07

Schjølberg, Ingrid. Utvikler neste generasjons roboter. *Automatisering* [Journal] 2016-11-11

Skjong, Espen. Her er verdens første flygende passasjer-drone. *E24* [Internet] 2016-01-09

Spiten, Christine. Et øye under vann. *Scandinavian Traveler* [Journal] 2016-09-29

Stahl, Annette. Ser sykdom og gir friskere fisk. *Teknisk Ukeblad* [Journal] 2016-11-14

Sørensen, Asgeir Johan. Her er Norge verdensledende. Nå skal vi gjøre det til en milliardindustri. *Teknisk Ukeblad* [Newspaper] 2016-06-04

Sørensen, Asgeir Johan. Kan bli først i verden på førerløse passasjerferjer. *Adresseavisen* [Newspaper] 2016-06-10

Sørensen, Asgeir Johan. Magnus (21) så dronene ligge og slenge. Da kom ideen. *Teknisk Ukeblad* [Journal] 2016-09-25

Sørensen, Asgeir Johan. Norway Readies for Autonomous Ship Testing. *Marasi News* [Internet] 2016-10-10

Sørensen, Asgeir Johan. Selvkjørende kjøretøy blir vanlig. *Computerworld* [Newspaper] 2016-11-29

Sørensen, Asgeir Johan. Vil teste førerløse skip i Trondheimsfjorden. *Adresseavisen* [Newspaper] 2016-03-09

Sørensen, Asgeir Johan. Åpner testområde for ubemannede fartøy. *Gemini.no* [Internet] 2016-09-30

Sørensen, Asgeir Johan; Schjølberg, Ingrid; Utne, Ingrid Bouwer. Test site opens for unmanned vessels. *Gemini.no* [Internet] 2016-10-01

Sørensen, Kim Lynge. New Technologies Aid Arctic Operations. *Inside Unmanned Systems* [Internet] 2016-08-15

Torre, Pedro De La; Volden, Frode. Litt av en jobb!. *NRK* [TV] 2016-10-28

Zolich, Artur Piotr; Leira, Frederik Stendahl; Sørensen, Kim Lynge. Norge, en ledende aktør innen droneforskningen. *Luftled*, nr. 2 juni 2016 [Journal] 2016-06-01

Ødegård, Øyvind. Intervju på Jacobsen (P1+) om vrak ved Svalbard. *NRK* [Radio] 2016-09-05

Ødegård, Øyvind. Race to save hidden treasures under threat from climate change. *New Scientist* [Internet] 2016-06-16

Ødegård, Øyvind; Johnsen, Geir. Utforsker havets dyp. *UiT The Arctic University of Norway* [Internet] 2016-02-03

Ødegård, Øyvind; Johnsen, Geir; Berge, Jørgen. Undervannsrobot som oppfyller tre ønsker. *Forskning.no* [Internet] 2016-02-16

Approved by the
NTNU AMOS Board of Directors 17 February 2017

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

Contributors:
Key personnel at NTNU AMOS
Researchers at NTNU AMOS
Sigrid Bakken Wold

Artwork frontpage and other illustrations:
Bjarne Stenberg

Photography:
Thor Nielsen

Layout and print:
Fagtrykk Trondheim AS
NO-7038 Trondheim

NTNU
Norwegian University of
Science and Technology

Annual Report for NTNU AMOS 2016

NTNU – The Norwegian University of Science and Technology
Knowledge for a better world

NTNU AMOS – Centre for Autonomous Marine Operations and Systems
Marine Technology Centre
NO-7491 Trondheim, NORWAY

Phone: +47 (735) 95535
Fax: +47 (735) 95528
E-mail: contact@amos.ntnu.no

www.ntnu.edu/amos

Design og trykk: www.fagtrykk.no
Miljømerket trykkeri, lisensnr. 2041 0811